Collapse, environment, and society

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Historical collapse of ancient states poses intriguing social-ecological questions, as well as potential applications to global change and contemporary strategies for sustainability. Five Old World case studies are developed to identify interactive inputs, triggers, and feedbacks in devolution. Collapse is multicausal and rarely abrupt. Political simplification undermines traditional structures of authority to favor militarization, whereas disintegration is preconditioned or triggered by acute stress (insecurity, environmental or economic crises, famine), with breakdown accompanied or followed by demographic decline. Undue attention to stressors risks underestimating the intricate interplay of environmental, political, and sociocultural resilience in limiting the damages of collapse or in facilitating reconstruction. The conceptual model emphasizes resilience, as well as the historical roles of leaders, elites, and ideology. However, a historical model cannot simply be applied to contemporary problems of sustainability without adjustment for cumulative information and increasing possibilities for popular participation. Between the 14th and 18th centuries, Western Europe responded to environmental crises by innovation and intensification; such modernization was decentralized, protracted, flexible, and broadly based. Much of the current alarmist literature that claims to draw from historical experience is poorly focused, simplistic, and unhelpful. It fails to appreciate that resilience and readaptation depend on identified options, improved understanding, cultural solidarity, enlightened leadership, and opportunities for participation and fresh ideas.

historical disasters | Egypt | Mesopotamia | Fayum Oasis | Ethiopia

Rise and Fall of Civilizations

There has been inordinate fascination with societal collapse, an issue outlined in the introduction to this Special Feature (1). The concept has intuitive appeal but ambiguous meaning, and has been applied to states, nations, or complex societies, in the sense that such entities rise and flourish, but eventually disintegrate and fail. Sociopolitical organization, economic weakness, and environmental or demographic trends have received emphasis. Change takes a long-term cyclic rhythm, at first organizing, then expanding and integrating, before sinking in disorder. Systemic failure in one synergistic network may destabilize adjacent structures. Other open questions concern the scale of collapse, the time frames involved, the key elements that fail, and whether the outcome is cataclysmic or eventually allows restructuring. Not all breakdowns are alike.

This challenging concept and its attendant issues were first articulated by the Islamic historian Ibn Khaldun [after 1377 common era (CE)] (2), who identified the periodic rise and fall of dynasties as macrostructures in the history of sedentary civilizations. Beginning with the Roman Empire and continuing with its Islamic counterparts, he attributed demise to rural rebellions or outside invaders confronting a ruling hierarchy that had forfeited the solidarity of its supporters. Rather than a global history, Khaldun's work was an implicit critique of Islamic society that went beyond theological arguments. He faulted the greed and selfishness that came with power, at the expense of the common good.

Khaldun's writings were poorly disseminated, and Western interest in collapse was initially stimulated by Edward Gibbon (3), who, with laborious detail, attributed the decline and fall of the Roman Empire to moral decay and barbarian invasions, much like his predecessor had. Gibbon observed that Roman collapse had changed the sociopolitical map of Europe and the Mediterranean world, a transformation that continues to generate a secondary literature. Although Gibbon held to an ethical dimension, he recognized that Roman collapse could not be separated from historical processes that shaped the dynamic context of its time, and he was uneasy about the potential future failure of even more enlightened and powerful states.

When the archaeological discoveries of the 19th century revealed a periodic failure of kingdoms and empires across the Near East, the collapse model became a durable theme of social and historical discourse. However, the message shifted: whereas ephemeral Eastern civilizations regularly dissolved in chaos, the comparative durability of ancient Rome improved the prospect that Western Europe might endure indefinitely.

With the proliferation of biological analogues in the mid-1800s, ontogenetic or evolutionary qualities such as growth, maturity, and decline were used to interpret historical macrostructures. For social Darwinists, material culture became an index for the increasing achievements of civilization, in an era when the Industrial Revolution exuded the driving force of "progress." The West was seen as a new empire, wherein technology would assure unlimited economic growth. Problems could and would be fixed by technological innovation.

Oswald Spengler's *The Decline of the West* (1918–1922) (4) was written in the wake of a world war and before the Nazi ascendance. He redefined ontogeny in humanistic terms that included premonitions of the authoritarian state. His "winter" would coincide with a demise of abstract thought, accompanied by empowerment of the rich, and the rise of caesarian, demagogic leaders. Spengler saw a society in deep crisis, and his prescient but pessimistic ideas anticipated the horrors of fascism and Stalinism. His insights remain pertinent for modeling alternative pathways of political resilience in the wake of collapse.

By contrast, the French authors of the *Annales* School chose a nonlinear track to capture the rich detail of regional histories, and to develop an interdisciplinary method in which millennial demographic waves served as a bellwether of key interactive processes (5–7). Disjunctures were attributed to competing economic systems, long-distance networking, warfare, or pandemics (8), ideas that gave impetus to world-system history (9–11). The *annalistes* eventually turned to more humanistic studies that introduced

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environmental variability as an integral part of historical process (12, 13).

Notable is the increasing diversity of perspectives about collapse, ranging initially from ethical and social, to ideological or ethnocentric, and eventually to interdisciplinary and systemic. The underlying ideas continue to echo. The salient concern today is the interface between environment and society, to require greater attention to social science and humanities perspectives. There has indeed been rapid growth of theoretical sophistication in regard to complexity and network theory, agent-based models, resilience theory, or tipping points. However, the challenge for a scientific study of historical collapse remains to develop comprehensive, integrated or coupled models, drawing upon the implications of qualitative narratives that go well beyond routine social science categories, to better incorporate the complexity of human societies (1).

Current research in historical collapse suggests a primary fascination with climatic change and environmental degradation as primary agents of change, but at the cost of less attention to the necessary cross-disciplinary integration. Indeed, the recent return to environmentalism is not about a fresh interest in the environment–society interface, but a continuing failure to appreciate the complexity of such interrelationships. At issue is not whether climatic change is relevant for sociohistorical change, but how we can deal more objectively with coupled systems that include a great tapestry of variables, among which climatically triggered environmental change is undeniably important. The *SI Text* reviews the problematic revival of environmental determinism in regard to the Akkadian collapse, as well as the purported societal passivity about anthropogenic degradation and potential future collapse. The Old World case studies range from early historical times to the threshold of globalization, with additional examples outlined in the *SI Text*, or presented in the various research articles of this Special Feature of PNAS. Examined at different levels of detail, these cases help single out more important, interactive variables, to estimate time scales for transformation, and explore the roles of preconditioning, triggering and reconstituting processes. The ultimate goal would be to design complex simulation models that incorporate sophisticated societal components and that can be validated (1).

This presentation attempts to transcend simple assumptions or truisms and monocausal explanations, by dissecting historical examples so as to illustrate the full palette of social-ecological variables and why they are so important for resilience within coupled systems. Some current models for change pay careful attention to biophysical variables that may affect feedbacks, but then go on to simply fit a group of societal factors into a few preconceived categories, supported by tertiary digests of no better than mixed value, to "explain" a particular outcome by assumed, axiomatic processes. Instead, our five case studies (later and in the *SI Text*) identify important, qualitative variables and track their roles and interplay in systemic outcomes. Although difficult to simulate, societal inputs and feedbacks are more common than environmental variables. The case studies also offer temporal parameters for transformation.

Anatomy of a Collapse: Old Kingdom Egypt

The historical cycle of the Egyptian Old Kingdom (14) closed shortly after the improbably long reign of Pepi II [~2278–2184 before CE (BCE)], the last significant ruler of the sixth Dynasty. Such long periods of rule can lead to issues of succession, and royal authority promptly collapsed at the death of Pepi II, judging by a cluster of approximately 20 powerless kinglets, marking the seventh-eighth dynasties, a very short time span, perhaps from 2181 to 2160 BCE. Egypt broke apart into several feuding provincial powers, controlled by members of the old elite or a novel genre of warlords, to be reunited through force of arms after approximately 2040 BCE by a new, 11th Dynasty.

Didactic Literature. An interval of approximately 120 to 200 y (ref. 15, table S7; ref. 16, p 464), known as the First Intermediate Period (dynasties 9–10), represents a radical sociopolitical transformation, documented by written records and archeology. Instead of burial near Memphis, the rich or powerful began to build rock tombs near their provincial land-holdings. Wealth was dispersed to new centers, with economic growth, artistic and cultural change, and a shift to a different style of social complexity (17). Some of the elite were deeply disturbed by the course of events, leading to a body of didactic literature (labeled as instructions, lamentations, or prophecies) that became literary classics during the Middle and New Kingdoms, when they were used in the schooling of young scribes.

Few such tracts have the necessary authenticity of historical descriptions, but they do represent an insider perspective on Egyptian cultural memory of a painful transition (ref. 18, p. 109–113). The autobiography of Ankhtifi, a southern provincial governor [ninth Dynasty, ~2120 (?) BCE], was inscribed in a rock-cut tomb. The full list of woes enumerated had not been previously used in literary convention, and was not a mere figure of speech. The text elliptically reports rampant civil war, famine, and starvation caused by Nile failure, mass dying or aimless dislocation of starving people, cannibalism (*sic*), wanton tomb or cemetery violations, and dispossession of the elite. Other, less authentic admonitions of the era amplify the themes of poverty, anarchy, and the upending of social roles. The basic message is a breakdown of the "cosmic order" and social justice, perhaps in the wake of an environmental disaster. However one chooses to interpret such writings, there was no central government, while justice, order, or respect for tradition fell by the wayside during the nadir of collapse, presumably the seventh to eighth dynasties.

Onset of Economic Decline. During the sixth dynasty, central authority was steadily diluted by privileges granted to courtiers around the throne. Mortuary temples were already built for pharaohs of the fourth dynasty, institutions that engaged groups of priests, paid by the treasury in perpetuity, whereas such foundations and their farms were exempt from taxes, much as nonprofit corporations are today. Gradually such privileges were accorded to other powerful men at court, a pattern accelerating during sixth Dynasty times until a significant part of the prime lands was removed from the fiscal rolls, even as the state continued to support the upkeep of mortuary cults ("entitlements").

Economic decline also resulted from breakdown of the vital foreign trade, mainly carried out over the entrepot of Byblos (now Jubail, Lebanon). Cedar and fir were imported for shipbuilding, or luxury goods such as wine and olive oil, for elite use. Pharaoh is likely to have profited greatly from such transactions, but archeology shows that, during the reign of Pepi II, Byblos was destroyed by the Akkadians, its Egyptian imports ending abruptly (19) and then interrupted for 250 y. That would have cut off a critical source of royal revenue, weakening pharaoh's personal power.

Environmental Trigger. Inferred from the admonitions, Nile failures are quite plausible in view of the limnological record of Lake Turkana: fed to approximately 90% by the Omo watershed in mountainous western Ethiopia, an area with climatic conditions similar to those of the Blue Nile. Prominent and dated beach ridges indicate a sporadic, early to mid-Holocene overflow of this nonoutlet lake, through a series of swamps to the Sobat and White Nile rivers (20). Together with diatom assemblages, alkalinity levels, and Omo detrital silicates, the lake levels offer a proxy record for Blue Nile behavior, but the chronology is only approximate (21). A decrease in Omo material approximately 2800 (calibrated years) BCE was followed by an abrupt change in water chemistry, to a closed, alkaline-saline lake, approximately 2400 BCE. This coincided with a late fourth Dynasty shift to downcutting (i.e., channel incision) of the Nile at Giza

(22), implying a pattern of poor or indifferent floods that would only inundate parts of the flood basins. Omo influx was minimal approximately 2100 BCE, but sharply greater 2000 to 1800 BCE, before declining again. Considering the partial match of these rough dates, it is possible but unproven that Nile failures may have helped trigger collapse of the old kingdom.

Civil Wars. The Egyptian record after Pepi II not only points to dynastic instability, but also includes direct and indirect evidence of civil wars during the ninth to 11th dynasties. Permanent reunification of Egypt toward approximately 2016 BCE required several bloody campaigns until the victory of a Theban dynasty over the northern center of Heracleopolis, but even then the Delta remained to be subjugated (23, 24). The Theban vizier later usurped the throne, waging intermittent warfare to ascend to the kingship as Amenemhet I (~1985–1956 BCE) of the 12th dynasty, against vigorous opposition by some of the elites (ref. 16, p. 493–495; and ref. 25). He was later assassinated. He and his successors had been supported by the provincial warlords of Middle Egypt (24), who retained considerable power until approximately 1850 BCE, when a new king phased out or eliminated the office of provincial governors—potential military contenders—and returned Egypt to a more traditional, centralized autocracy. Demilitarization followed, with reemergence of a middle class (ref. 16, p. 506; and ref. 25), ending 300 y of intermittent warfare and civil strife. The collapse after Pepi II had evidently unleashed unwelcome feedbacks that repeatedly favored destructive military unrest, variously coupled with both elite contestation and resilience. The didactic literature implies that the goal of reunification remained central to the cosmic order ascribed to by key national power groups.

Concatenation. The details marshaled here illustrate the immense complexity of collapse. The economic prosperity of Egypt had declined through the course of the sixth Dynasty, inversely to the growing wealth and power of now-hereditary provincial governors. The expansion of mortuary endowments, fiscal stagnation, decentralization of authority, and loss of hegemony over eastern Mediterranean trade had served to precondition Egypt for collapse across 160 y or more. Nile failures probably unleashed a severe subsistence crisis that helped trigger an economic breakdown near the end of Pepi II's reign, but other factors were also involved (17, 26). Contending elite groups may originally have used an impending crisis of succession to undermine royal legitimacy, in an effort to steer more power to the provinces. However, they discovered that social anarchy is difficult to contain when institutional structures falter. Amid social chaos and insecurity analogous to that of modern Somalia, ancient Egypt experienced political simplification as the contestants repeatedly resorted to armed force.

A concatenation of triggering economic, subsistence, political, and social forces probably drove Egypt across a threshold of instability, setting in train a downward spiral of cascading feedbacks. In the end, a semblance of the cosmic order was restored, with the support of new elites, but with the heavy hand of military men, even as the echoes of civil war continued to reverberate until the authoritarian rule of the Pyramid Age was reinstated (ref. 17; pp. 118–119 and 130–131). The initial breakdown took a few decades, but the processes of collapse played out on a centennial scale, as did reconstitution (16).

This detailed analysis, with the advantage of a body of fragmentary but rich, written records, helps illustrate the true complexity of collapse. It involved more than an impersonal network of systemic interactions. It encompassed people, admittedly at cross purposes and with incomplete information, who ultimately sought to bring their country back together, consonant with their vision of the cosmic order. In the persons of military leaders and conflicted elites, one can gain a glimpse of the ambiguous notions that political and social resilience imply.

Autopsy of Another Collapse: New Kingdom Egypt

A second historical example better illuminates the socioeconomic components and processes of national failure, with the important benefit of specific economic records. Under the 20th Dynasty (~1187–1064 BCE) (27, 28), Egypt devolved from a powerful state to a divided nation in which authority had been usurped by a high priesthood that controlled the well-endowed temples as well as military forces, ready to engage in civil war. However, instead of recovery, Egypt came to be ruled by foreign dynasties.

When Did Decline Begin? The pharaoh Merenptah shipped a great amount of grain to alleviate famine in the wavering Hittite empire at approximately 1210 BCE, suggesting a major drought in Anatolia but food abundance in the Nile Valley. Then, in 1207, he had to fend off a determined invasion of Libyans in alliance with several "Sea Peoples," perhaps mobilized by the same environmental crisis in western Anatolia and the Aegean world.

Three further foreign onslaughts confronted Ramesses III (1185–1153 BCE) of the 20th dynasty. He managed to defeat the fleet of Sea Peoples amid the Delta marshes in 1174. However, these powerful raiders had already destroyed all other states of the eastern Mediterranean, including Egyptian hegemony in the Levant, to terminate traditional commercial relationships, with implications for widespread economic depression (26). Although Ramesses III still carried out a major building program and sent an expedition to Punt, he made an unusual offering to the Nile in 1179, to propitiate the river and seek good floods (29). High-level malfeasance and corruption surfaced in 1157, and the king was victim to a harem conspiracy at the time of his death.

The severity of gathering economic problems can be gauged by unprecedented strikes and rioting, because of insufficient food and unpaid wages for the royal artisans (in 1156). The vizier could turn up only half the wheat needed, because the temple storage facilities were empty. The food supply had failed, the king's authority was brazenly challenged, and Egypt was patently in decline.

Process of Devolution. On the accession of the king's son (Ramesses IV) (30), the royal workmen were paid off with food and silver, not by the king's treasury but by representatives of the High Priest (ref. 28, p. 607). Conflict between institutions is implied. Rolling food shortfalls continued, with runaway inflation. Grain prices, with respect to nonfood products, had begun to increase in 1170, eventually increasing to eight times and occasionally 24 times the standard price. Inflation peaked at approximately 1130, stabilizing at approximately 1110, with food prices falling rapidly at approximately 1100 to 1070 (31). This was the first subsistence crisis actually recorded in accounting books (~1170–1110 BCE). Hardship was exacerbated by insecurity caused by Libyan marauders (1117–1101), favoring rural flight and declining productivity.

Royal power and prestige were fading. Rock for monumental construction was no longer quarried after 1151, and an 1135 expedition to the turquoise mines of Sinai was the last. A new High Priest had himself represented the same size as the king (~1113), suggesting a more direct appropriation of power. Looting of the royal and private tombs at Thebes was underway with high-level complicity, and became scandalous under Ramesses XI (1099–1069 BCE), who did not use his completed tomb in the Valley of the Kings, and apparently chose to be buried in northern Egypt. This last monarch attempted to avoid the inevitable, calling in the Egyptian viceroy from Nubia, who battled the High Priest's army and, interestingly, assumed the notable title Overseer of the Royal Granaries (1086 BCE), while controlling southern Egypt for a decade.

Thereafter, a new High Priest disenfranchised the pharaoh as the provider of life and safeguard of the cosmic order, declaring him a simple agent of the

supreme god Amun (32). By 1075, Ramesses XI was a mere figurehead, residing in the Delta, with Upper Egypt ruled by the High Priest in the name of Amun, while Nubia became independent. Usurpation had been completed and Egypt was divided.

Evaluation. The subsistence crises from 1170 to 1110 were preconditioned by (*i*) debilitating wars to repel invaders, (*ii*) the loss of Mediterranean commerce, (*iii*) official corruption, and (*iv*) a lack of support from the priesthood controlling the temple granaries. However, the repeated waves of wild inflation strongly suggest that famines were triggered by Nile failures (33). At Memphis, floods had declined by approximately 6 m from approximately 1300 to 1100 BCE, a trend that was paralleled in Nubia, where sand dunes swept the floodplain and agriculture had to be abandoned (22).

However, decline of the redistributive economy continued even after the famines were overcome, while Egypt was divided as a state and fragmented as a country. Unlike the admonitions literature of the First Intermediate Period, which espoused a return to traditional cosmic values, during the 20th Dynasty, there was no persuasive exhortation toward a moral high ground (18). Instead there is the "Tale of Woe," which laments arbitrary rule, violence, excessive tax demands, falsified units of measure, hunger, and the breakdown of the social contract (ref. 34 and ref. 18. pp. 291–293). Egypt was impoverished and demoralized, and at the end of the new kingdom, swelling disaster did not provoke political or social resilience. Instead the ascendant military–priestly caste exhibited little vision. The once integrative national bureaucracy had failed amid pervasive corruption, giving way to a chaotic and superstition-driven theocracy that paraded as a "rebirth." Nubian and Libyan dynasties followed in control.

There was, in fact, no reconstitution or significant restoration until the indigenous Saite revival, which began under a vigorous king in 664 BCE, almost a half millennium after initial disintegration. The end of new kingdom Egypt was a quite different experience than old kingdom collapse, with breaching of multiple thresholds that apparently created virtually irreversible changes.

Insights from Islamic Mesopotamia

Lower Mesopotamia has qualified as an irrigation society for approximately 6000 y. Much of the central alluvial plain was archaeologically surveyed by Robert Adams (35–39) before field research in Iraq came to a halt. Such survey data are dependent on pottery dating and are not an ideal proxy for population trends, but cautious inferences are possible. Premodern settlement density peaked during Sasanid (i.e., new Persian empire) times (226–637 CE), after which the population eventually collapsed by as much as 95%, toward the time of the destruction of Baghdad by a Mongol-led coalition in 1258 CE. That span of approximately 700 y is hardly "abrupt" by any reckoning, but it does not take into account that there were in fact two distinct collapses.

During the 630s CE, the Arab Conquest destroyed the Sasanid Empire militarily, replacing its administrative institutions, bringing with it a new elite and many settlers from Arabia. Islam replaced Zoroastrianism and Christianity as the leading religion. Indigenous speakers of Aramaic, Persian, and Arabic gradually amalgamated with immigrant Arabs to forge a new, Arabic-speaking ethnicity (40). Sociopolitical collapse was complete by approximately 642 CE, but with some evidence of earlier decline in response to population loss from the Justinian plague (541 CE), exacerbated by many decades of inconclusive warfare between the Sasanids and Byzantium until shortly before the Arab onslaught.

Repeated innovations in irrigation strategy can be traced in Mesopotamia, beginning with the Sasanids, who developed a novel system that opened up large areas for cultivation with a lattice of intersecting canals to enclose polygons of variable size, with waters distributed from the Euphrates and Tigris (ref. 35, pp. 200–241). Although favoring salinization in the long run, such basins could be flooded annually, to optimize the use of available water. A great canal, the Nahrawan, was led from the Tigris near Samarra to irrigate the eastern side of the river. However, the Sasanid network had begun to deteriorate in the wake of catastrophic floods after 628 CE that destroyed or silted up transverse canals, as the Tigris shifted and caused the growth of a vast swamp, accompanied by a high water table favoring salinization of the lowermost alluvial plain. After the Conquest, the Sasanid system was abandoned and new master canals were cut along different, more traditional trajectories, but watering less than half of its previous area. This catastrophic disjuncture suggests fundamental social disruption in the wake of the Arab Conquest, as the administrative superstructure was replaced by a new elite, probably unfamiliar with Sasanid methods (ref. 35, p. 218).

However, Mesopotamia promptly recovered and, after 750 CE, became the heartland of the powerful Abbasid Empire, based on a modest recovery of the irrigation system and the tribute from far-flung provinces. It reached its apogee under the legendary Harun al-Rashid (786–809 CE) but then began to decline as a result of wasteful expenditures and rapacious tax farming (40). Late Abbasid misgovernment and weakening imperial hegemony were punctuated by serious rebellions and the wanton Seljuk destruction of Khuzistan at approximately 1015 CE (41), until the economy was in full decline and the Nahrawan canal ceased to function (35). Islamic historians and poets have eulogized the size, wealth, and scholarship of Baghdad at the moment of its demise and depopulation in 1258, but such descriptions actually harked back 300 y, to the heyday of Abbasid civilization (42). Instead the archaeological evidence shows that the irrigation system had collapsed well before any Mongol destruction (35), and was not reconstructed until the 20th century. Unfortunate is that the early Islamic archives of Iraq had only been partially studied before their destruction by fire in 2003.

There were then two Islamic collapses in Mesopotamia, the first in the wake of the Arab Conquest at approximately 640 CE, the second beginning in the 10th century and concluding with Mongol plundering of what was left of Baghdad in 1258 CE. The first collapse spanned approximately a century, the second as long as 300 y, and the responsible processes were very different. However, consistent themes were war, land use change, and irrigation, or fiscal mismanagement.

The collapse of new kingdom Egypt and of Islamic Mesopotamia involved the persons and sources of indigenous power, both worldly and divine, and the external forces of chaos may have weighed heavily on sociocultural consciousness. The outcomes probably were traumatic, but in the end, Egypt, as a society and an environment, was more resilient than Mesopotamia and continued to function with a modicum of success. The failure of the irrigation society of Mesopotamia was an ecological tragedy, leading to the wasteland reported by 19th century travelers (43).

Integration: A Didactic Model for Historical Collapse

Discourse on historical collapse has tended to be macroscopic and generalizing, based on limited comparative research. Little attention was given to the politicoeconomic markers of state devolution, or the strategic solutions that may have been attempted but failed. Rarely considered were the attributes of cultural identity that might have been rejected or transformed. The preceding analyses emphasize the wide range of variables involved, the complicated time frames, and the roles of textual or insider information.

Interpreted with the aid of a simplified, heuristic model (Fig. 1), the case studies examined here and in the *SI Text* suggest that the complexity of the social–ecological interface is as much about interrelationships as it is about the identification of stressors. Related questions are comprehensively discussed later, but, being grounded in historical examples, a

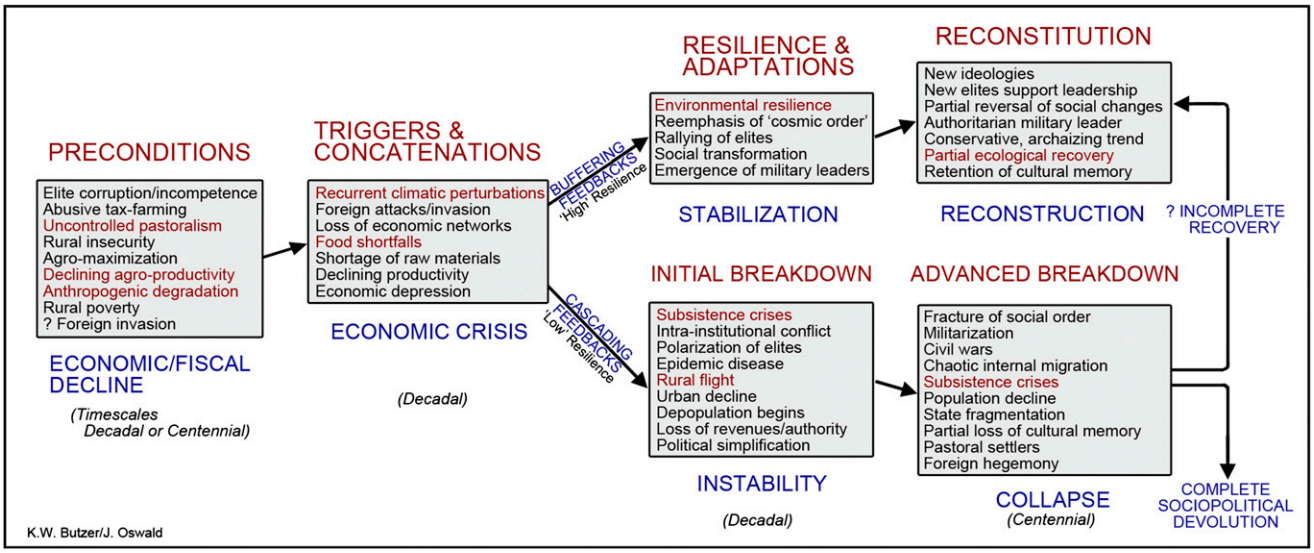


Fig. 1. A conceptual model for historical collapse, situating the variables and processes of stress and interaction discussed in the text. Timescales range from multidecadal to centennial. Alternate pathways point to important qualities of resilience. Red superscripts identify stages that are elaborated by blue subscripts. Environmental components (red within boxes) are secondary to sociopolitical factors.

word of caution is due that the insights of the model are not applicable to current issues without modification.

Inputs, Triggers, and interactive Variables. The process of breakdown typically begins with economic or fiscal decline caused by external and internal inputs, some of which are long-term and precondition a system to suboptimal performance or weakened social-ecological response. Others are short-term but intense, serving as triggers (or, in combination, as concatenations) for a deep economic crisis provoking rapid change. Such inputs may activate cascading (positive) feedbacks that sustain or enhance negative trends, to create instability in the early stages of breakdown. If instead there is a resilient response, leading to beneficial readaptations, devolution may be slowed or stabilized. In the longer term, such pathways may allow reconstitution and reconstruction or, alternatively, continuing breakdown and eventual collapse.

Degradation of soils or other biotic resources (deforestation, ground-cover removal, soil erosion, or groundwater depletion and salinization) represents incremental damage that lowers thresholds for more rapid down-the-line change, particularly in conjunction with incompetent administration, destructive land use, or rural flight. Declining resource productivity increases pressure on the environment and may precondition an environmental subsystem for failure.

Effective climatic inputs are most likely to be high-recurrence perturbations, such as excessive rains or floods, and more persistent, decadal anomalies (such as severe droughts) that serve as triggering mechanisms, impacting a stressed or degraded environment to unleash more catastrophic forms of hydrological behavior or slope failure (44–46). Climatic variables can also precondition the environment by accelerating degradation, or disastrous floods may provoke outbreaks of epidemic disease. Population decline or the disintegration of economic networks may reinforce environmental feedbacks, compromising food production as well as access to external information, food supplies, markets, and raw materials.

However, the case studies (*SI Text*) indicate that environmental inputs mainly played supporting roles in a train of events set in motion by institutional incompetence or corruption, civil strife and insecurity, invasion, or pandemics. Here government failure is likely to precondition the system, with external war as another potential trigger. Protracted conflict may well be destructive for infrastructure, food production, manufacturing, market access, and demographic success. It can also bring sociopolitical domination of one group by another, enslavement, rural insecurity, and socioeconomic or ethnic conflict, stimulating everyday violence and rural abandonment.

Finally, it bears emphasizing that decline or collapse can be either consequence or cause of sociopolitical devolution. It may undermine traditional customs, law, and institutions, particularly in the case of conflict between different elite groups, so as to reduce sociocultural resilience. Outcomes are difficult to predict because of the interplay of multiple, cascading, or buffering feedbacks (Fig. 1).

Time Frames. Duration of the processes favoring decline or recovery helps to identify the processes of devolution as well as the elasticity of resilience. Drawing from the experience of the historical case studies, Fig. 1 suggests that a preconditioning economic decline typically spans decades or centuries. Contrary to frequent claims of "abrupt" collapse, the triggers that bring economic crisis are more likely to operate at a multidecadal scale. The first stage of stabilization or instability may also be fairly rapid, whereas a more complex reconstitution or complete breakdown is likely to span a century or more. Time frames would also be affected by the absence of rapid or sustained means of communication in earlier historical eras.

Environmental Resilience. "Resilience" of human ecosystems can be usefully subdivided into a triad of intersecting environmental, political, and cultural components. Negative feedbacks resist, dampen, or reverse change. Preconditioning factors may also impose a degree of stability. Perhaps little appreciated is that some environmental systems are more resilient than others in regard to anthropogenic or climatic change and their cascading feedbacks.

Politicoeconomic structures in Europe have been less vulnerable to collapse than those of arid lands in the Near East. Great irrigation networks that supported large populations in Mesopotamia were fragile because they are artificial, i.e., relatively homogeneous, managed, and hierarchical systems that require much capital or labor to maintain, and exponentially more to reconstruct. The desert may return after abandonment, not because of damage to the environment but because of human disengagement. Critical here are land tenure, the mobilization of labor, and the

complexity of large irrigation systems. When rent, tax, or work demands become impossible, Near Eastern peasants have historically abandoned their villages to enter the broad spectrum of semipastoral pursuits that fill the gap between cultivation and fully mobile nomadic herding. Beyond the reach of the tax collector, such semipastoralists reverted to simpler lifeways in what was a fiscal wasteland, but not a deserted landscape. This was the condition of lower Mesopotamia until the late 19th century (43). That is the true meaning of socioecological collapse in irrigable, Near Eastern desert environments. Multiple domains and scales of institutional displacement imply fairly resilient "final" regimes (47), i.e., reconstitution will be very difficult.

In southern Europe, by contrast, mixed farming is less specialized but also less productive. Temporary abandonment plays out at intermediate scales in compartmentalized but selected biohabitats. It does not turn the land over to desert, and renewed settlement requires more modest community coordination or start-up investment. In Greece, with great spatial complexity, there were periodic waves of soil erosion caused by climate or land use (48, 49), but urban life and agriculture soon resumed, with the necessary investment to mitigate much past damage. In other words, Mediterranean and many Western agrosystems are relatively stable and less liable to "catastrophic" simplification. Environmental resilience—not impairment—is the basic difference between southern Europe and the Near East in the *longue durée* of demography and agrarian production. It is not a matter of Eastern decadence or Western cultural fortitude.

What may be true at a large, global scale is more complicated at the regional or local level. Deforestation or land clearance can put diversity at risk, but the often higher inherent diversity of secondary vegetation, with its many commensal plants, may actually impart greater resilience to stressed biotic communities. In northern Greece, the prehistoric pollen record shows that plant diversity was greater in areas of degraded vegetation (50), whereas in Spain, Mediterranean scrub (i.e., *monte bajo*) offers more nutritious graze, especially after burns, through increased legume dispersal (51). It also opens opportunities for subsequent conversion to olive groves or vineyards. Mediterranean people regard *monte bajo* not as "waste" but as land in reserve, which is used for local pastoralism and wood gathering, but can be converted to more productive orchards when markets improve (46). Early forestry experts from higher latitudes were disturbed by the open nature of Mediterranean woodlands, even though they were looking at old-growth formations (44, 45). Deforestation is therefore not a simple process that can be equated with human degradation, and reforestation with invasive or ornamental trees does not qualify as recovery. Similar misunderstandings can arise about tropical savanna woodlands (52), as to the role of fire, or about the age and origin of grassy mosaics in woodland (53).

Facile generalizations are equally inappropriate in arid lands. The conjoined Tigris/Euphrates floodplain with its radial canal systems is vulnerable to violent floods that destroy riverbank cities (36–38), explode in crevasses, shift courses, overwhelm canals with silt, or raise the water table of desert plains liable to salinization. By contrast, artificial irrigation in Egypt was superimposed on the natural rhythm of existing flood basins, to enhance the height and duration of the inundation while flushing soluble salts downstream.

Egypt could support permanent settlement even with little artificial irrigation, although at a much lower carrying capacity. That was not the case in Mesopotamia, where breakdown of complex canal networks would force wholesale abandonment of agriculture. Such differences underscore the distinct environmental and land use histories of Egypt and Mesopotamia. Environmentally triggered collapse in Egypt would be comparatively short-term and have modest demographic impact, but in Mesopotamia it could be catastrophic.

In specific ecological contexts and at different spatial scales, environmental inputs mobilize certain processes, define thresholds, follow time-paths, and favor outcomes that may be distinctive. Beyond the exotic rivers of the Near East, precipitation anomalies vary spatially and temporally. However, environmentally grounded crises are culturally screened and perceived, so as to affect vulnerability, resilience, and response, as well as the timescales at which underlying processes can be addressed. Environmental elasticity may be critical in the mitigating of collapse, or in the ability of a society to carry on.

Political Resilience. In conjunction with the case studies, analogues from anthropology and political ecology suggest that ruling families and elites tend to support the state, if only in self-interest. The trauma of collapse in ancient kingdoms can be reversed by new dynastic cycles, during which rulers rebuilt their societies with the support of new elite groupings, but not necessarily with the same identity or political center. Whatever the complex rationales of statehood or power, elites can come together to support a new ruler in rebuilding similar or modified administrative and ideological structures. In this way, ruling dynasties were periodically able to reassert the authority of kingship in Egypt and Mesopotamia.

Repeated simplification and cyclic change in Assyria in approximately 1800 to 1600 BCE is documented and interpreted by Yoffee (54) as a net shift to greater centralization. First, the power-sharing councils of traditional nobility disappeared. Eventually, the generals of the huge army assumed that role, while the traditional kin and landholders were displaced from lower management roles by civil servants, with a work force increasingly formed of non-Assyrian deportees, to favor non-Assyrian cultures and belief systems. In this late Assyrian case, political transformation was not catastrophic but part of a strategic progression that manipulated institutional roles.

States may collapse because of incompetent rulers, but surviving members of the old elites, together with new allies of diverging persuasion, will eventually help pick a new candidate to support. In other words, even in the wake of substantial change, the political class represents a key force of resilience and potential stabilization, in tandem with the religious establishment. Important is the rallying of elite groups and institutional bureaucracies, perhaps with a shift of ideology. The convergence of such fundamental interests may not be able to halt a downward cycle of collapse, but they are basic to subsequent regeneration through the revival of dynastic ambition, the imposition of law and order, and a redefined symbolic cohesion of national interests.

The darker side of revival is that it may not involve a reassessment or reaffirmation of old ideals embedded in cultural memory. Many or most decisions would be made under stress, with the goal of securing or consolidating power. Disagreements may have been contested by populist demands but are more likely to be settled by military force. Traditional values may fall into oblivion in the course of destructive violence, as the old order falters. In the end, the new elites probably cast their lot with a new military leader, as Spengler foresaw (4), more adept at neutralizing internal or external enemies than championing the higher ideals of governance. Interlinear clues from Egypt and Mesopotamia imply that the emerging social contract is more likely to have been authoritarian than enlightened, with older rules of class distinction and land tenure rigidly enforced. In general, the chances are that an exploitative political economy will not favor conservationist land use (46).

Cultural Resilience. Sociopolitical structures appear to be the most fragile components in collapse of archaic states or traditional societies, in which there was no role for the equivalent of contemporary, community-based structures. The case studies suggest that hierarchical orders were "simplified," probably with a transfer of authority. Formal institutions, dynasties, national symbols, and states come and go, but was this accompanied by a loss of religious or linguistic identity? Either or both have frequently changed in the

course of human history, without engendering collapse. However, both are critical facets of self-identification and cultural or social memory, and their loss can mark ethnic transformation.

Was cultural integrity involved, in the sense of community values, rituals of solidarity, age-cohort and sex relationships, strategies for subsistence, stewardship of multigenerational resources, and general lifeways? Such traits circumscribe a tighter radius of "who we are," "what we do," and "how we make a living," that presumably underlie a dominant social rationale and are quite resistant to change. However, the fact that cultures develop unique situational constraints is critical in understanding the processes of resilience. For example, the cultural integrity of Egypt or Mesopotamia—similar at some levels but not at others—has remained intact across many millennia, despite changes of language, religion, and ethnic identity.

Collapse commonly involves demographic change. A population may be decimated by warfare, disease, famine, foreign colonization, migration, expulsion, or total elimination. Large-scale expulsion and deportation are verified for the late Assyrian and Neo-Babylonian empires, symptomatic of an unstable balance between human resources and imperial ambitions. An inability of civilian authorities or religious ritual to redress the ravages of epidemic disease can spur social unrest, and high losses leave land uncultivated to cause subsequent famine. Strong demographic declines may not lead to collapse, but they can put institutional structures under severe stress, or favor ecologically harmful land use strategies of short-term survival.

Since the 15th century CE, major Mediterranean cities were dependent on Polish wheat imported by sea (55). Such continental economic networks are a stabilizing force, and their breakdown can have global demographic repercussions. Parallel cycles of urban growth or decline throughout Eurasia have been evident during the past 2500 y (9, 11), and have been linked to climatic perturbations (56) or, more likely, manpower shortages in the wake of pandemics. However, as the disastrous modern famines of Ireland (1840s) and India (1940s)—each with a mortality of 1 million or more lives—bear out, millennial or centennial demographic waves cannot be explained by single factors.

Constructions of the nature of collapse, like contemporary opinions of "failing states," must be sensitive that some criteria are inherently Eurocentric, not cross-cultural. Peoples with different historical experience do not necessarily share Western perceptions of stress, chaos, or disaster. This might indirectly affect the political economy of traditional social contexts. Given structural constraints and elite demands, there may well have been little room for community decision-making if a top-down leadership screens the compatibility of new ideas, adaptive strategies, and behavioral feedbacks. Although cultural resilience may have been mainly passive in a longer historical frame, there are counter-examples such as indigenous rebellions in Ptolemaic Egypt (57) or bloody slave and peasant revolts in Abbasid Mesopotamia (40). Whether uprisings achieved their desired results is dubious because they often appear to have provoked tighter repression. Cultural resilience is a tricky quality. It may help resist change, but only up to a certain threshold, beyond which cascading feedbacks can trigger unanticipated social or political transformation.

From Past to Present. Several generalizations can now be drawn from the case studies and discussion of historical collapse:

i) The most common input attribute at an early stage of every breakdown (except possibly Axum) was institutional failure, viz. incompetence, loss of economic networks, corruption, or dynastic crises.

ii) Civil war or invasion was as critical as any form of climatic forcing.

iii) Environmental degradation such as soil erosion is only documented for Axum and the Black Death (see *SI Text*), in contrast to climatic perturbations that helped trigger breakdowns in Old and New Kingdom Egypt, the Fayum, or Mesopotamia on the eve of the Islamic conquest.

iv) Demographic retraction was prevalent during or after collapse, commonly linked with pestilence. The Black Death is the classic example of a pathogen-driven, catastrophic depopulation.

v) Ideological shifts accompanied collapse in New Kingdom Egypt, the Fayum, Mesopotamia, and Axum, in part overlapping with foreign intrusion or ethnic change.

In other words, poor leadership, administrative dysfunction, and ideological ambivalence appear to be endemic to the processes of collapse. War or climatic perturbations possibly served as triggering mechanisms, but environmental degradation does not appear as a universal variable. Demographic decline was either a coagency or a delayed result of change, except for the Black Death. Collapse was a consequence of multiple factors, reinforced by various feedbacks and partly balanced by resilience, with unpredictable outcomes. The comparative importance of societal versus environmental inputs seems to favor the social side.

If the number of case studies is expanded to include others from this Special Feature, it adds only two examples of collapse [Greenland, the Maya (58, 59)], but four instances in which resilience allowed fundamental change without simplification or breakdown (the prehistoric Levant, Iceland, Cyprus, Colonial Mexico (44, 60–62)]. Reviewing subsistence crises in western Europe after approximately 1200 CE identifies food riots, peasant revolts, and wars of religion, but no radical sociopolitical transformations until the French Revolution. This more recent historical experience also suggests that environmental or economic disasters do not necessarily lead to social breakdown or collapse.

However, the late Medieval to early Modern period in western Europe did see a continuing and fundamental shift of food producing and distribution strategies, to a good degree in response to a series of wrenching environmental crises. After the Medieval Warm Period (~850–1280 CE), and until the Little Ice Age (~1570–1860 CE), there were three centuries marked by extreme climatic perturbations (63, 64) analogous to the seemingly unprecedented disturbed weather of the past 25 y. These environmental changes and their context are encapsulated in the *SI Text* because they suggest a transition of focal length, organization, and available information, in approaching the intersection of diachronic and synchronic perspectives.

The modernization of western European food production during the past millennium, as painful as it was for the many, was decentralized and protracted. It reveals unexpected resilience and the ability of people under extreme stress to try new solutions. It appears that, after overcoming initial, ideological dissonance, people can indeed come together to support change. The key differences with our historical case studies are structural. Ancient Egypt and Mesopotamia were authoritarian, with no feasible bottom-up options, whereas western European societies were, to a surprising degree, corporate and participatory (65), with a high tolerance of individualistic behavior (66). Change is difficult to implement in dictatorships that cow their citizens by force, silence dissent, and stifle initiative. Megacrises can best be confronted by flexibility and the cohesion of most social classes or components within a particular polity or region.

Historical monitoring across long timescales is vital to situate the present or apply to contemporary or future problems of sustainability (67–69). However, it does not provide simple prescriptive insights about the risks of global change, counter-ecological behavior, pandemics, or sustainability. What it does do is suggest that all too much of the alarmist literature that claims to draw from historical experience is poorly focused, simplistic, and unhelpful. Our diachronic investigation implies that the specter of historical collapse has become

a red herring. The pundits should instead turn their attention to information diffusion and socioeconomic integration, across class lines and different spatial scales.

Modern states, even when marginally dysfunctional, have significant advantages over their archaic counterparts in terms of administrative experience, information, and an increasingly educated and engaged citizenry. Given the increasing frequency and scale of disastrous climatic events, today there is an urgent need for competing societal elites to downplay ideological difference and face the realities of global climate change, anticipating its momentous socioeconomic implications. These diachronic insights highlight the importance of information: better understanding, enlightened leadership, and opportunities for broad participation and fresh ideas.

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