Global Environmental Change 84 (2024) 102792

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Are civilizations destined to collapse? Lessons from the Mediterranean Bronze Age

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ARTICLE INFO

Keywords:
Bronze age
Societal collapse
Resilience
Risk
Networks
Geopolitical conflicts

ABSTRACT

As the world faces multiple crises, lessons from humanity's past can potentially suggest ways to decrease disruptions and increase societal resilience. From 1200 to 1100 BCE, several advanced societies in the Eastern Mediterranean suffered dramatic collapse. Though the causes of the Late Bronze Age Collapse are still debated, contributing factors may include a "perfect storm" of multiple stressors: social and economic upheaval, earthquake clusters, climate change, and others. We examined how collapse might have propagated through the societies' connections by modeling the Eastern Mediterranean Late Bronze Age trade and socio-political networks. Our model shows that the Late Bronze Age societies made a robust network, where any single node's collapse was insufficient to catalyze the regional collapse that historically transpired. However, modeled scenarios indicate that some paired node disruptions could cause cascading failure within the network. Subsequently, a holistic understanding of the region's network incentive structures and feedback loops can help societies anticipate compounding risk conditions that might lead to widespread collapse and allow them to take appropriate actions to mitigate or adapt societal dependencies. Such network analyses may be able to provide insight as to how we can prevent a collapse of socio-political, economic and trade networks similar to what occurred at the end of the Late Bronze Age. Though such data-intensive analytics were unavailable to these Bronze Age regions, modern society may be able to leverage historical lessons in order to foster improved robustness and resilience to compounding threats. Our work shows that civilization collapses are preventable; we are not necessarily destined to collapse.

1. Introduction: The Late Bronze Age civilizations and their collapse

From approximately 1700–1200 BCE, the Late Bronze Age in the Aegean and Eastern Mediterranean featured a number of centralized societies whose monuments endured in some instances for centuries. The key players included the Mycenaeans on mainland Greece, who succeeded and somewhat subsumed the Minoans on Crete, New Kingdom Egypt, Babylonia, Cyprus, Assyria, the Hittite empire in Anatolia, cities in the region of Western Anatolia, and the cities of Canaan, including the international entrepot Ugarit (Fig. 1).

Dramatic changes at the end of the Late Bronze Age attest to the abrupt collapse of several of these long-standing and interconnected societies and the transformation of others (Cline, 2021). During this period, regional trade, expressions of art and culture, and prevailing systems of palace governance disintegrated, inaugurating a far less connected period with diminished societal complexity. Scholars have proposed causes for this regional collapse, with particular emphasis upon social strife, famine, or an invasion by the 'Sea Peoples,' but no theories have proved conclusive. We know that the Late Bronze Age Collapse struck cosmopolitan societies which had prospered for centuries. Why did they suddenly become untenable? What precipitated the widespread collapse? This has been the subject of scholarly debates for several decades now.

Archaeological and textual remains document a high degree of connectivity between Bronze Age polities prior to the Collapse, largely borne from necessity. For instance, the bronze metal that constituted the era's technical innovation contained 90 % copper and 10 % tin and

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https://doi.org/10.1016/j.gloenvcha.2023.102792
Received 30 January 2023; Received in revised form 31 October 2023; Accepted 8 December 2023
Available online 5 January 2024

required international trade to secure the components, namely copper from Cyprus and tin from either Turkey or Central Asia, i.e., Afghanistan, Uzbekistan, and Tajikistan (see (Powell et al., 2022; Powell et al., 2021).

A minimum of 175 exchanges between 28 separate polities can be either documented or inferred from archaeological remains and textual inscriptions in the period prior to the Late Bronze Age Collapse (Cline, 2021). The connections include marriages between various empires, war, disease, military aid, and material exchanges. Access to critical materials, such as the tin from Central Asia, fueled the development of long-distance trade routes beyond the Eastern Mediterranean, and subsequently fostered the exchange of other goods (grains, wood, spices, pottery, precious metals, and various luxuries) between the Aegean and Eastern Mediterranean polities. Evidence of exchange of certain foods with South Asia has been recently discovered, including sesame, soybeans, turmeric, and possibly bananas (Scott et al., 2021).

Such societal complexity provided the foundations of population growth and the formation of robust societies. These societies had previously survived both natural disasters (e.g., the earlier eruption of Santorini) and socio-political cataclysms (e.g., the conflict between Egypt and the Hittites, including the Battle of Kadesh) to continue advancing: regional complexity was sustained and grew. Harvests improved, international trade expanded, diplomatic and cultural exchanges grew broader in scope (Cline, 2021; Manning et al., 2014; Marco, 2018).

Towards the end of the Late Bronze Age, many disruptions reoccurred but with differences from earlier periods. In particular, new studies involving lake sediments, stalagmites in caves, and coring from lagoons, in regions stretching from Italy and Greece to Turkey, Syria, Lebanon, Israel, and Iran, have produced evidence of drier and colder conditions, especially towards the end of this period (see, e.g., Cline, 2021; Finné et al., 2019; Kaniewski et al., 2020; Kaniewski et al., 2019; Kaniewski et al., 2019; Langgut et al., 2015; Weiberg and Finné, 2018). Such a regional change in climatic conditions likely created local disruptions to food sources and water, and possibly other critical functions like sea travel and fire management.

During the early 12th century BCE, many cities were abandoned or violently destroyed. This Collapse decreased regional trade, reduced literacy, and lowered socio-political and economic organization. Over time, bronze was replaced by the more locally accessible iron, hence the name for this succeeding period: the Iron Age.

These regional changes occurred rather suddenly and probably unexpectedly, begging the question: what could produce this outcome? It has been suggested (Cline, 2021) that a "perfect storm" of calamities, including drought, famine, disease, invaders, and earthquakes, coalesced to create the disaster. However, while this may suggest *what* happened, it does not answer *why* or *how* the interconnected network and its components collapsed. The current study models the Late Bronze

Fig. 1. The Late Bronze Age world. Here we have combined modern place names (Mainland Greece, Cyprus) with the contemporary names of regions that no longer exist (Ugarit, Canaan, Hittite Empire). The node "Western Anatolia" is a conglomerate of several polities on the western coast of modern-day Turkey, including some that were occasionally subsumed in the Hittite Empire, as shown.

Age Collapse to examine whether the Collapse arose following link failures within the connected political and commercial networks of the Late Bronze Age societies.

2. Materials, methods, and network description

This analysis combines network science and the wealth of information available from the Late Bronze Age Collapse. Our network contains ten nodes: nine of these represent the most important regions of the Late Bronze Age in this area, namely Assyria, Babylonia, Canaan, Crete, Cyprus, Egypt, Mainland Greece, Hittites, and Western Anatolia, while a tenth node represents Ugarit, an international city with substantial archaeological and textual evidence.

Our network contains two layers: commercial and political, based primarily on the archaeological and textual evidence presented in the book *1177 BC: The Year Civilization Collapsed* (Cline, 2021). While recognizing that our network uses an incomplete historical record, we hope that the ample extant evidence approximates the most salient features of these two layers. Fig. 2 shows the modeled network's political and commercial layers.

The *political* links represent diplomatic ties between nodes: friendly relations and mutual defense pacts, as seen in treaties between the Hittites and the Egyptians or between the Hittites and at least one ruler of Wilusa (i.e., Troy). We regard such political ties as undirected links, meaning the exchange relationship is reciprocal rather than originating at one node and ending at the other. We distinguish four levels of strength for these political ties: $w = 1,\ldots,4$. There are $E_1 = 30$ links in the political layer.

The *commercial* links represent trade flows between the nodes, including pottery, metal and glass ingots, and luxuries like beads and ivory. We regard such trade flows as directed, although goods almost always flow in both directions. We again distinguish four levels of strength for these trade links: $w = 1,\ldots,4$. There are $E_2 = 89$ directed links in the commercial layer.

We have limited our analysis to links of strength 3 and 4 in both layers, producing a two-layer interdependent network of $N = 10$ nodes, $E_1 = 21$ undirected political links, and $E_2 = 54$ directed commercial links. This limiting created a sufficiently sparse network to stress test while still reflecting the archaeological record. Since $E_2 = 54$ directed links connect each node pair in both directions, we further reduce them to 27 undirected links.

2.1. Compounding threats and determining node stability

The network model tests the hypothesis that node failures cause link failures that can affect the node at the link's other end. We assume that a

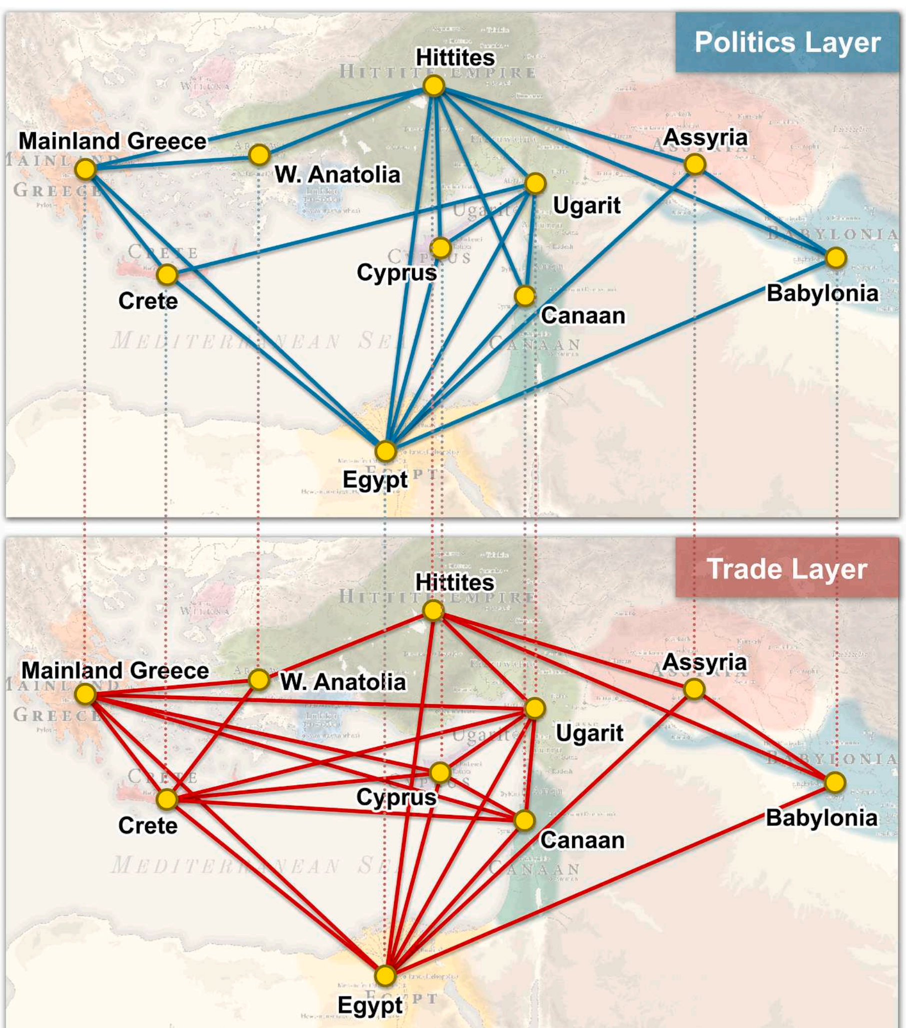

Fig. 2. Late Bronze Age network. The network consists of interdependent political (top, blue) and commercial (bottom, red) layers. The vertical dashed lines between the two layers display interdependencies between the layers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

node will "collapse" when a sufficient number of its links collapse. Moreover, we also assume that the commercial and political layers are interdependent and that the well-being of a node in one level depends upon its state in the other layer. Consequently, a node failure in one layer causes the failure of the same node in the other layer (Bárta et al., 2019; Boccaletti et al., 2014; Buldyrev et al., 2010; Gao et al., 2015; Kivelä et al., 2014; Shekhtman et al., 2015). If multiple nodes collapse simultaneously, or nearly so, that could cause a catastrophic failure to take place far more rapidly than if only one or two nodes collapse.

We feel that these assumptions are justified for a variety of reasons, including the fact that the loss of diplomatic support could expose a region to attacks from external aggressors, threatening its existence. Similarly, the loss of commercial ties threatens the economic prosperity and can weaken political and diplomatic capabilities.

As such, we have set the following rules for node stability:

1) To be considered stable overall, a node must be stable in both layers. If a node destabilizes in one layer, it destabilizes in the other layer.
2) To be considered stable in the political layer, a node needs to have at least two links to other stable nodes.
3) To be considered stable in the commercial layer, a node needs to retain at least one third of its commercial links with other stable nodes.

We chose these rules because in running our computer modeling, we found that demanding only one political tie for continued stability in the political layer made the network too robust. However, demanding that each node has at least three political ties causes the original network to collapse without any initial stimuli. Hence, the only non-trivial choice is two links per node for stability.

Similarly, in the commercial layer, we tested having a node or region fail if it loses irreplaceable goods when a link is cut. For example, if the node depends on gold but has only a single link for acquiring gold, cutting that commercial link would cause the node to fail. However, the data regarding the goods traded between the various nodes or regions via their commercial links is insufficient to proceed using this method. In the end, we characterized continued stability in the commercial layer using the remaining fraction of commercial ties (p). Experimentation using that $p > 1/3$ of original ties are necessary for stability, or $p > ½$, or $p > 2/3$ produced similar results, so we have chosen the smallest of these.

Existing archaeological and textual records indicate which of the Late Bronze Age societies failed, but after 3,000 years the order in which they failed is not clear. Therefore, we considered any of the societies which failed catastrophically to be potential instigators of the Collapse. These include the Hittites in Anatolia, the Mycenaeans on Mainland Greece, the Minoans on Crete, the southern Canaanites, the inhabitants of western Anatolia, and the citizens of Ugarit.

To stress-test the network, we examined all possible 1, 2, 3, and 4-region/node removal combinations. In each experiment, we removed the initial node(s) and checked the stability of the remaining nodes in the political layer and the commercial layer. Due to layer interdependence, we postulated that a node remains stable if it is stable in both layers. If a node becomes unstable in either layer, we removed it from the network in both layers. We continued to remove nodes and examine network layers in a cyclical fashion until no additional nodes remained to be removed. We quantified the fraction (or, equivalently, the percentage) of removed nodes according to the initial stress:

$$D = \frac{N_r}{N - N_i}, \tag{1}$$

where N = nodes in the network, N_i = initial number of nodes removed during the stress-testing experiment, and N_r = unstable nodes after the initial removal of N_i nodes.

3. Results

As became evident during our modeling experiments, the Late Bronze Age network remains robust with respect to 1-node removals in eight out of the ten possible cases; the network remains stable if, for example, only Mainland Greece is removed, or only the Egyptians (Fig. 3a). However, in the two remaining 1-node removal cases (Mainland Greece and the Hittites), the networks lose one additional node each time, resulting in 11 % damage.

2-node removal had more effects on the Late Bronze Age network (Fig. 3b), but most of the 2-node removals still failed to damage the greater network. Twenty-seven of the 45 possible 2-node removal scenarios did not produce any network damage. An additional 15 of the 2-node removal scenarios destabilized less than three of the eight remaining nodes. However, the remaining three of the 2-node removal scenarios destabilized more than five of eight nodes. For instance, the removal of both Egypt and Ugarit left the network with only three stable nodes, and the 2-node scenarios of either both the Hittites and Egyptians or both the Hittites and Ugarit completely disintegrated the Bronze Age network.

Simultaneous removals of three and four nodes damaged to the Bronze Age network even more (see Fig. 3c and 3d), consistent with the scale of initial damage. Most of the damaging 3- and 4-node combinations include the damaging 2-node combinations just mentioned.

Overall, our stress-test experiments indicate interconnectedness made the Aegean and Eastern Mediterranean Late Bronze Age civilizations generally robust. Using our stipulated thresholds for collapse, the loss of any single node would be insufficient to create a cascade. However, our stress test of the network revealed a vulnerability to certain node combination failures: two 2-node combinations that could initiate cascading failures across the commercial and political networks. Both cases involve a failure of the Hittite Empire, one paired with a simultaneous failure of Egypt, and the second with a simultaneous failure of Ugarit. We will consider these below.

4. Discussion

The model predicted a cascading network failure if both Egypt and the Hittite Empire failed. However, although Egypt was affected by the Late Bronze Age Collapse, it did not totally collapse despite periods of disorganization and even anarchy during the next few centuries (Cline, 2024). Thus, this modeled paired failure could not have occurred and we dismiss this scenario.

The second instance, involving the simultaneous failures of Ugarit and the Hittite Empire, is historically plausible because both entities did collapse around this time. We know, from both textual and archaeological evidence, including letters sent between the last Hittite and Ugaritic kings as well as the Hittite viceroy at Carchemish (Cline, 2021; Pardee, 2003) with further references), that despite famine, Ugarit was operating normally until an attack by unknown aggressors caused the city's destruction and complete abandonment. Meanwhile, the Hittite Empire also experienced famine and the capital city Hattusa was abandoned for an unknown reason and later destroyed. Although it is not possible to pinpoint precisely when each node collapsed, nor which collapsed first, it is possible that they collapsed closely together in time (Cline, 2021; Kemp and Cline, 2022).

The archaeological record shows that after both Ugarit and the Hittite Empire collapsed, neither recovered. Similarly, our modeled network shows that their paired failure would have been sufficient to collapse the Bronze Age network entirely due to the structure of the network itself.

Fig. 4 shows the progression of this collapse scenario. The loss of Ugarit's and the Hittite Empire's nodes and links sufficed to destabilize Western Anatolia, Cyprus, and Canaan (Fig. 4a). Their subsequent link failures compounded the existing commercial network gaps caused by the loss of Ugarit and the Hittites and caused the collapse of Mainland

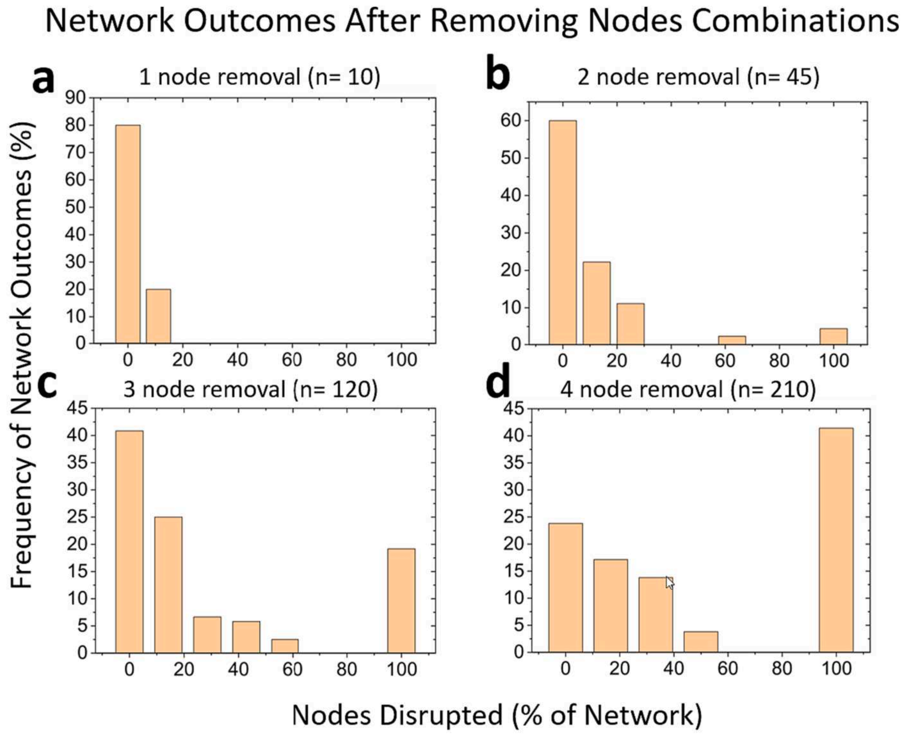

Fig. 3. Stress testing of the Late Bronze Age network. Summary of Network Scenario Outcomes Shown are the distributions of network damage realizations following the removal of (**a**) 1, (**b**) 2, (**c**) 3, and (**d**) 4 nodes simultaneously.

Greece and Crete (Fig. 4b). These commercial link losses would then have affected Egypt (Fig. 4c), and finally Assyria and Babylonia (Fig. 4d). We therefore believe that our modeling has demonstrated at least one avenue by which this previously robust network could have experienced cascading collapse. However, there is more to the discussion, as follows.

4.1. Robustness and resilience of civilizations

The restructuring and reformation of complex systems over time can involve cycles of growth, conservation, collapse, and renewal at distinct scales, as described by the concept of panarchy (Gunderson and Holling, 2002; Newhard and Cline, 2022). Within panarchy, collapse is a precondition for restructuring, which can yield a system that is more robust to emergent constraints or conditions. Such was the case with the eventual recovery after the Late Bronze Age Collapse. During this time a new alphabet, which was easier to learn and use than the earlier writing systems such as Linear B and cuneiform, was standardized and disseminated by the Phoenicians, and iron replaced bronze as the metal of preference (Cline, 2024).

Collapse can occur when entrenched systems are maladaptive for new circumstances, but is collapse truly inevitable, as some scholars argue (Quigley, 1979; Spengler, 1991; Toynbee, 1987)? We believe that the patterns and origins of collapse may suggest answers for these questions.

Large-scale environmental changes taking place during the Late Bronze Age may not have been perceived as great threats by contemporary individuals, especially by those who did not experience the impact of a changing climate directly (Haldon et al., 2020). Yet, to take the macro-scale view, node vulnerability could have become more pronounced as the climatic patterns changed. For example, declining crop yields could reduce tribute and taxation to palace leadership, who in turn lost capacity to provide for their cities or maintain armies to ward off invaders. An inability to feed one’s people could exacerbate risks of internal social upheaval and external competition for scarce resources (see, i.e., (Maran, 2023). Such competition threatens dwindling international trade, creating scarcity for traded commodities (Kaniewski et al., 2013; Vidal-Cordasco and Nuevo-López, 2021). At the same time, natural resource shortages could affect governance and security, such as the ability to safely transport goods in the presence of hungry residents and societal breakdown.

Additionally, these societies were interconnected to an extent not often seen in antiquity either before or after. Societies can exist without links, but we hypothesize that these links allowed the societies to grow beyond the constraints imposed by their local resources. These nested dependencies produced a network with ample redundancy that promoted robustness and recovery if any single regional power were disrupted by disaster, but they also created the potential for cascading disruptions following multi-nodal failures. To invoke the Heraclitus Law (or Principle), the factors that enabled the rise and success of the network may have also contributed to its demise (Bárta, 2019).

The robustness of the network suggests that a single crisis was unlikely to trigger the regional collapse of the 12th century BCE. However, climate change could have undermined individual nodes, making them vulnerable to shocks that they had previously weathered (Weiberg and Finné, 2018). The region’s changing climate increased the probability for simultaneous and independent node disruptions.

Our model results suggest that Egypt, Assyria, and Babylon would have been the last nodes to be affected, as the collapse cascaded within the Late Bronze Age network. The historical record provides some validation and corroboration for this: in the aftermath of the Collapse, Egyptian civilization was diminished but endured, while both the Assyrians and the Babylonians demonstrated resilience and adaptation following the collapse of their neighbors (Cline, 2024). The Assyrians successfully survived a century or more of drought and related misfortunes, including attacks by the Aramaeans and Babylonians, and eventually expanded in the 9th century BCE, culminating in the Neo-Assyrian Empire.

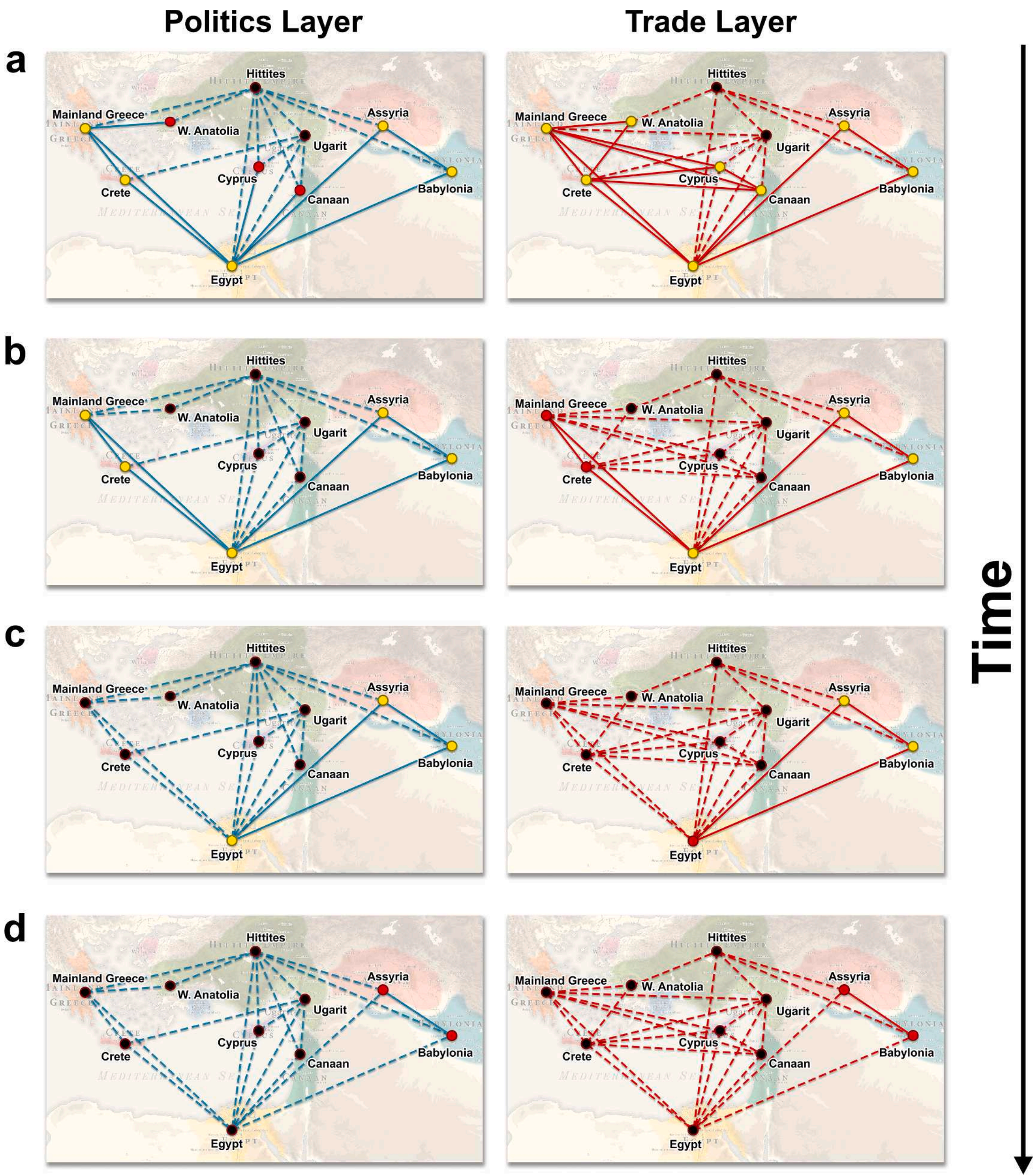

Fig. 4. Simulation of the Aegean and Eastern Mediterranean Late Bronze Age Collapse. Reviewing the regional network (political layer on the left in blue, commercial layer on the right in red), we simulated outcomes when Ugarit and the Hittite Empire were 'destroyed' (decoupled from the broader regional network). Panel 4a displays the collapse of the Hittites and Ugarit, causing W. Anatolia, Cyprus, and Canaan regions to lose a substantial number of links in the politics layer. 4**b**, the subsequent destruction of W. Anatolia, Cyprus, and Canaan leads to the weakening of Mainland Greece and Crete in the commercial layer. 4**c**, the destruction of Mainland Greece and Crete causes Egypt to lose 6 of the 8 original commercial ties. 4d, the destruction of Egypt weakens Assyria and Babylonia as well, leading to the complete disintegration of the Late Bronze Age network. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Comparisons to today

The Late Bronze Age shares some similarities with the modern world, including dependencies on scarce materials — instead of tin, for instance, we rely on oil, lithium (Narins, 2017), or phosphorus (Chowdhury et al., 2017). We also now face climate change affecting a global trade system so connected and interdependent that one blocked trade route can cause worldwide ramifications (de Bodt et al., 2021). Likewise, societal dependence upon cyber access and other transmission infrastructure presents opportunities for disruptions to societal systems.

Our analysis demonstrates that network complexity can amplify events in non-linear fashions, causing networks which appear robust to nevertheless collapse when disrupted in a specific way. Further study of the ancient situation indicates vulnerabilities perhaps apparent only in hindsight for at least some of the societies during the Late Bronze Age Collapse (Cline, 2024; Manning et al., 2023; Maran, 2023). The city of Ugarit maintained normal operations until immediately before the destruction of the city (Cline, 2021): thus systems can operate and appear functional even while the underlying foundations are eroding. Failure to recognize and adapt to new circumstances can allow the appearance of normality and continuity while the system is at risk of catastrophic failure from a disruption that might have previously been considered routine.

Our society may be entering a similar circumstance as the Late Bronze Age: the changes of a shifting environment can increasingly disrupt societies simultaneously and create conditions for cascading disasters. Potentially, this could reduce the complexity needed for modern standards of living to function, such as infrastructure, security, and trade, including aspects that make life enjoyable, e.g. the arts. The COVID-19 pandemic has already revealed structural weaknesses. These include brittle supply chains and understaffed emergency response organizations. Globally, many regions are unprepared for and increasingly vulnerable to climate change. With Russia's 2022 invasion of Ukraine, many countries reliant on the latter's considerable wheat exports have already suffered the effects of a conflict in which they are not directly involved.

4.3. Final observations

Interconnectedness is a vehicle for prosperity when a network's nodes are stable, but it similarly conveys discord when nodes begin to fail. Modern civilization has the advantage of far greater foresight by model projections as well as the ability to critically examine the past, including impacts of climate change (Burke et al., 2021). The two strategies frequently proposed to manage expected disruptions are mitigation and adaptation. Mitigation is any action that prevents or reduces disruption, while adaptation makes changes to better support critical functions in a changing threat environment.

However, even as modern civilization has increasingly demonstrated our ability to anticipate future disruptions, large systems are not always able to maneuver to respond, either by mitigation or adaptation. This has been poignantly demonstrated by the coronavirus pandemic, both in the global inability to contain the pandemic and cascading disruptions in economic and educational systems, among others, as the pandemic progressed. Other examples of "long fuse, big boom" used to describe the Late Bronze Age Collapse (Kemp and Cline, 2022) include water scarcity in the Colorado River or the depletion of the Ogallala Aquifer. Thus, the lessons of past collapse due to a failure to mitigate or adapt are very much applicable to modern challenges, even when our predictive powers are markedly better.

The network analysis of the Late Bronze Age in the Aegean and Eastern Mediterranean provides a cautionary tale in which interconnectedness plays a crucial role in propagating disruption. The contemporary world is characterized by melting glaciers and soaring temperatures that weaken individual nodes and make compounding disruptions more likely. While we are not necessarily destined to collapse, now is the time to build resilience into our modern interconnected system and plan for a tomorrow that may be very different from today. The Late Bronze Age Collapse demonstrates what we must strive to avoid. This Bronze Age interconnected network flourished for centuries prior to the collapse. Though we cannot know whether decision makers of the Late Bronze Age realized that their societies had lost resilience or whether they subsequently tried to adapt, the ruins of destroyed cities across the Aegean and Eastern Mediterranean regions bear witness that whatever choices they made in the end did not save them.

Authors contribution

IL and BT developed idea of the paper and provided guidance; MK and SG conducted research and developed first paper draft; EP and KR supported research; EC provided historical data and interpretation; All authors contributed in paper preparation and revisions.

Funding sources

This research project was supported by the U.S. Army Engineers Research and Development Center Funding Laboratory Enhancements (FLEX-4) Program.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The views and opinions expressed in this paper are those of the individual authors and not those of the US Army or other sponsor organizations. The authors thank the *Climate Change* and *History Research Initiative* team at Princeton University for their support. The authors also acknowledge the guidance and mentorship of John Haldon and Miguel Centeno. The authors further acknowledge George Siharulidze for graphical assistance, and Hendrik Wuckelt (Cyowari) for cartographic illustration and mapmaking.

References

Bárta, M., 2019. The Heraclitus Law. In: Bárta, M., Kovár, M. (Eds.), Civilisations: Collapse and Regeneration: Addressing the Nature of Change and Transformation in History. Academia, Praha, pp. 245–268.

Boccaletti, S., Bianconi, G., Criado, R., Del Genio, C.I., Gómez-Gardenes, J., Romance, M., Sendina-Nadal, I., Wang, Z., Zanin, M., 2014. The structure and dynamics of multilayer networks. Phys. Rep. 544, 1–122.

Buldyrev, S.V., Parshani, R., Paul, G., Stanley, H.E., Havlin, S., 2010. Catastrophic cascade of failures in interdependent networks. Nature 464, 1025–1028.

Burke, A., Peros, M.C., Wren, C.D., Pausata, F.S., Riel-Salvatore, J., Moine, O., de Vernal, A., Kageyama, M., Boisard, S., 2021. The archaeology of climate change: The case for cultural diversity. Proceedings of the National Academy of Sciences 118.

Chowdhury, R.B., Moore, G.A., Weatherley, A.J., Arora, M., 2017. Key sustainability challenges for the global phosphorus resource, their implications for global food security, and options for mitigation. J. Clean. Prod. 140, 945–963.

Cline, E.H., 2021. 1177 BC: The Year Civilization Collapsed, Revised Edition. ed. Princeton University Press.

Cline, E.H., 2024. After 1177 BC: The Survival of Civilizations. Princeton University Press, Princeton.

de Bodt, E., Cousin, J.-G., Dupire-Declerck, M., 2021. The CSR Supply Chain Risk Management Hypothesis Evidence from the Suez Canal Ever Given Obstruction. Available at SSRN 3867169.

Finné, M., Woodbridge, J., Labuhn, I., Roberts, C.N., 2019. Holocene hydro-climatic variability in the Mediterranean: a synthetic multi-proxy reconstruction. The Holocene 29 (5), 847–863.

Gao, J., Liu, X., Li, D., Havlin, S., 2015. Recent progress on the resilience of complex networks. Energies 8, 12187–12210.

Gunderson, L., Holling, C.S., 2002. Panarchy: Understanding transformations in human and natural systems. Island Press, New York.

Haldon, J., Chase, A.F., Eastwood, W., Medina-Elizalde, M., Izdebski, A., Ludlow, F., Middleton, G., Mordechai, L., Nesbitt, J., Turner, B.L., 2020. Demystifying collapse: climate, environment, and social agency in pre-modern societies. Millennium 17, 1–33.

Kaniewski, D., Marriner, N., Cheddadi, R., Fischer, P.M., Otto, T., Luce, F., Van Campo, E., 2020. Climate change and social unrest: A 6,000-year chronicle from the eastern Mediterranean. Geophys. Res. Lett. 47 (7), e2020GL087496.

Kaniewski, D., Van Campo, E., Guiot, J., Le Burel, S., Otto, T., Baeteman, C., 2013. Environmental roots of the Late Bronze Age crisis. PLoS One 8, e71004.

Kaniewski, D., Marriner, N., Cheddadi, R., Morhange, C., Bretschneider, J., Jans, G., Otto, T., Luce, F., Van Campo, E., 2019. Cold and dry outbreaks in the eastern Mediterranean 3200 years ago. Geology 47 (10), 933–937.

Kaniewski, D., Marriner, N., Bretschneider, J., Jans, G., Morhange, C., Cheddadi, R., Otto, T., Luce, F., Van Campo, E., 2019. 300-year drought frames Late Bronze Age to Early Iron Age transition in the Near East: new palaeoecological data from Cyprus and Syria. Reg. Environ. Chang. 19, 2287–2297.

Kemp, L., Cline, E., 2022. Systemic Risk and Resilience: The Bronze Age Collapse and Recovery. In: Izdebski, A., Haldon, J., Filipkowski, P. (Eds.), Perspectives on Public Policy in Societal-Environmental Crises: Risk, Systems, and Decisions, 207–23. Springer, Cham, Switzerland.

Kivelä, M., Arenas, A., Barthelemy, M., Gleeson, J.P., Moreno, Y., Porter, M.A., 2014. Multilayer networks. Journal of Complex Networks 2, 203–271.

Langgut, D., Finkelstein, I., Litt, T., Neumann, F.H., Stein, M., 2015. Vegetation and climate changes during the Bronze and Iron Ages (∼ 3600–600 BCE) in the southern Levant based on palynological records. Radiocarbon 57 (2), 217–235.

Manning, S.W., Höflmayer, F., Moeller N.,, Dee, M.W., Ramsey, C.B., Fleitmann, D., Higham, T., 2014. Dating the Thera (Santorini) eruption: Archaeological and

scientific evidence supporting a high chronology. Antiquity, 88(342), 1164–1179. Cambridge Core. https://doi.org/10.1017/S0003598X00115388.
Manning, S.W., Kocik, C., Lorentzen, B., Sparks, J.P., 2023. Severe multi-year drought coincident with Hittite collapse around 1198–1196 bc. Nature 614 (7949), 719–724.
Maran, J., 2023. The Demise of the Mycenaean Palaces: The Need for an Interpretative Reset. In: Jung, R., Kardamaki, E. (Eds.), Synchronizing the Destructions of the Mycenaean Palaces. Austrian Academy of Sciences Press, Vienna, pp. 231–253.
Marco, D.P., 2018. Kadesh, beyond the Conflict: The Hittites in Egyptian "Minor" Documents. Conference poster for "Conflict in Ancient Culture" at 5th Annual Birmingham Egyptology Symposium, University of Birmingham, Birmingham (UK).
Narins, T.P., 2017. The battery business: Lithium availability and the growth of the global electric car industry. Extr. Ind. Soc. 4, 321–328.
Newhard, J.M.L., Cline, E.H., 2022. Panarchy and the Adaptive Cycle: A Case Study from Mycenaean Greece. In: Izdebski, A., Haldon, J., Filipkowski, P. (Eds.), Perspectives on Public Policy in Societal-Environmental Crises: Risk, Systems, and Decisions, 225–35. Springer, Cham, Switzerland.
Pardee, D., 2003. Ugaritic Letters, in: The Context of Scripture. In: Archival Documents from the Biblical World, Vol. 3. E. J. Brill, Leiden.
Powell, W., Frachetti, M., Pulak, C., Bankoff, H.A., Barjamovic, G., Johnson, M., Mathur, R., Pigott, V.C., Price, M., Yener, K.A., 2022. Tin from Uluburun shipwreck shows small-scale commodity exchange fueled continental tin supply across Late Bronze Age Eurasia. Sci. Adv. 8 (48), eabq3766.
Powell, W., Johnson, M., Pulak, C., Yener, K.A., Mathur, R., Bankoff, H.A., Godfrey, L., Price, M., Galili, E., 2021. From peaks to ports: Insights into tin provenance, production, and distribution from adapted applications of lead isotopic analysis of the Uluburun tin ingots. J. Archaeol. Sci. 134, 105455 https://doi.org/10.1016/j.jas.2021.105455.
Quigley, C., 1979. The evolution of civilizations: An introduction to historical analysis. Liberty Fund.
Scott, A., Power, R.C., Altmann-Wendling, V., Artzy, M., Martin, M.A., Eisenmann, S., Hagan, R., Salazar-García, D.C., Salmon, Y., Yegorov, D., 2021. Exotic foods reveal contact between South Asia and the Near East during the second millennium BCE. Proc. Natl. Acad. Sci. 118.
Shekhtman, L.M., Shai, S., Havlin, S., 2015. Resilience of networks formed of interdependent modular networks. New J. Phys. 17, 123007.
Spengler, O., 1991. The decline of the West. Oxford University Press, USA.
Toynbee, A.J., 1987. A Study of History: Volume I: Abridgement of Volumes I-VI. Oxford Paperbacks.
Vidal-Cordasco, M., Nuevo-López, A., 2021. Resilience and vulnerability to climate change in the Greek Dark Ages. J. Anthropol. Archaeol. 61, 101239.
Weiberg, E., Finné, M., 2018. Resilience and persistence of ancient societies in the face of climate change: a case study from Late Bronze Age Peloponnese. World Archaeol. 50 (4), 584–602.

Further reading

Weiberg, E., Bonnier, A., Finné, M., 2021. Land use, climate change and 'boom-bust' sequences in agricultural landscapes: Interdisciplinary perspectives from the Peloponnese (Greece). J. Anthropol. Archaeol. 63, 101319. https://doi.org/10.1016/j.jaa.2021.101319.
Linkov, I., Trump, B.D., 2019. The science and practice of resilience. Springer International Publishing, Cham.