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Environmental determinism in Holocene research: causality or coincidence?

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The past decade has seen a revival of environmental determinism in palaeoenvironmental research, with palaeoclimatic shifts implicated in the collapse of many past civilizations. Implicit in these studies is a belief that the observed cultural transitions can be causally related to the magnitude of climatic change. However, examination of the processes of these declines suggests that many exhibit patterns characteristic of complexity cascading within self-organized systems. If so, the nonlinear nature of these systems' responses to external forcing means that the assumption of causality in many of these cases should be considered questionable.

Key words: *Akkad, environmental determinism, palaeoclimate, marginality, nonlinearity, civilization collapse*

Introduction

The idea that a society's physical environment can control its cultural development is long established, though it could claim to have suffered more than most from shifts in intellectual fashion. For much of the second half of the twentieth century, environmental determinism was shunned by all but a few geographers. However, from the mid-1990s onwards a series of high-profile palaeoenvironmental studies have appeared showing apparently strong correlations between climatic change and catastrophic cultural collapses (cf. Diamond 2005). Despite this, many researchers (e.g. Erickson 1999; Sluyter 2003) still treat ideas of environmental influence with suspicion, and such scepticism is perhaps justified. As will be argued in this paper, causal relationships in complex environment–culture interactions can be less straightforward than they appear: major events do not always require major causes.

The concept of 'environmental determinism' received its first explicit treatment by the Baron de Montesquieu (1977) in 1748. In Montesquieu's cosmology, the mores of European, Asian and 'barbarian' cultures were intimately connected to global climatic patterns; human nature was thus a construct that could be related to the environment by scientific laws. The colonial expansion of the European powers in the eighteenth and nineteenth centuries gave added impetus to such studies, as the empire builders came into contact with climates and cultures markedly different to their own (Grove 1997). The late nineteenth and early twentieth centuries saw the culmination of this mechanistic tradition, as the imperial powers of the West sought to justify their colonial activities with a glut of pseudo-Darwinian proofs of their superiority (Livingstone 1992). However, this was to be the final flourish of classical environmental determinism. With the emergence of a new generation of geographers after the Second World War, the drive towards quantification, anti-colonialism and the backlash against Nazi-tainted eugenic theories combined to produce a new paradigm that found the precepts of determinism a juvenile embarrassment (Frenkel 1994).

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Despite this, a concern with environmental influence lingered on in parts of the academic community, with the *Annales* school (Le Roy Ladurie 1971; cf. Shermer 1995), climatic historians (Manley 1958; Lamb 1966 1995) and archaeologists (Sanders 1973; Bryson *et al.* 1974) all making occasional forays into the field. Such studies were to remain infrequent until the 1990s, when concern over anthropogenic impacts on global warming and a growing appreciation of the magnitude and rapidity of Holocene climatic change (Chambers and Brain 2002) combined to produce an intellectual climate suddenly sympathetic to the idea of environmentally triggered catastrophes (deMenocal 2001; Berglund 2003). With the advent of this new paradigm, palaeoenvironmental researchers have produced numerous studies showing apparent correlations between climatic change and cultural collapse. Notable examples include the Egyptian Old Kingdom (Manzanilla 1997; Hassan 2001), Akkad (Weiss *et al.* 1993; Cullen *et al.* 2000; Weiss and Bradley 2001), Harappa (Shinde *et al.* 2001; Staubwasser *et al.* 2003), Norse Greenland (McGovern 1994; Barlow *et al.* 1997; Arneborg *et al.* 1999) and the Iron Age of Western Europe (Van Geel *et al.* 1996; Tinner *et al.* 2003; Barber *et al.* 2004a). There has been particular interest in pre-Colombian American civilizations, including the Tiwanaku (Ortloff and Kolata 1993; Binford *et al.* 1997; Williams 2002) and Moche (Van Buren 2001; Dillehay *et al.* 2004) cultures of Peru, the Classic Maya (Hodell *et al.* 1995 2001; Haug *et al.* 2003) and the Anasazi of the south-western US (Lekson and Cameron 1995; Jones *et al.* 1999).

These collapses vary in nature; some, such as the 700 BC decline in Western Europe (Van Geel *et al.* 1996; Tinner *et al.* 2003; Barber *et al.* 2004a) were gradual declines involving long-term shifts in settlement patterns. However, the most striking studies involved the sudden collapse of advanced civilizations: the Akkadian, Egyptian, Mayan and Moche declines were of a scale and rapidity that seemed impossible to explain purely by cultural means. One of the most influential of these studies was Weiss *et al.*'s (1993) analysis of the Akkadian collapse. Akkad was the world's first major empire, stretching from the headwaters of the Tigris and Euphrates to the Persian Gulf (Weiss *et al.* 1993). From 2600 BC onwards, the disparate agricultural communities of the region were transformed into a series of populous, urbanized statelets; increasing levels of political and economic centralization culminated in the unification of the region under the rule of Sargon of Akkad in the 23rd century BC. At the peak of its development, the civilization suddenly collapsed around 2200 BC; much of the northern part of the empire was depopulated and irrigated lands were abandoned to the desert. This collapse was simultaneous with the impacts of the 4200 BP climatic deterioration (Figure 1), whose impact on regional aridity was confirmed by aeolian deposition at archaeological sites (Weiss *et al.* 1993) and by palaeoclimate records from marine cores (Cullen *et al.* 2000). To the researchers, the implication that the abrupt collapse was driven by climatic change was beyond question.

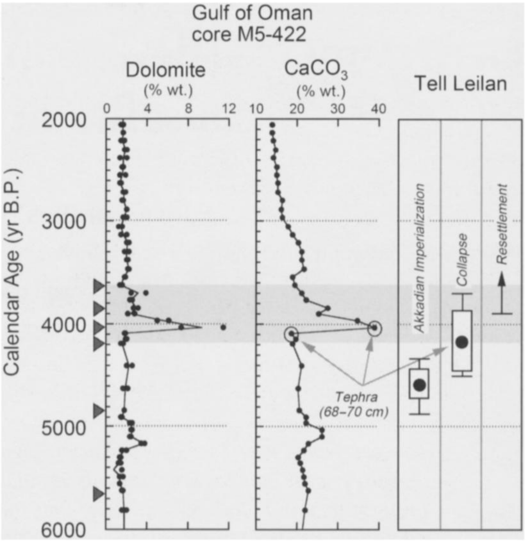

Figure 1 Mesopotamian palaeoclimate and the collapse of the Akkadian empire (from Cullen *et al.* 2001)

However, the primacy given to environmental influences in such studies represents a break with the post-war tradition of the archaeologists and anthropologists. Theirs was predominantly a 'soft' determinism, stressing the inseparable nature of environmental and cultural influences (e.g. Ortloff and Kolata 1993; Williams 2002), and viewing the physical environment as a delimiter of possible action rather than a prescriptive agency. Such concerns with culturally specific socioeconomic mechanisms are seldom viable in palaeoenvironmental studies. Palaeoenvironmental researchers typically operate over much wider scales of time and space, and need more universally applicable models. Most have settled for a basic 'black box' determinism, correlating climatic and cultural changes and largely neglecting the processes involved. Tentative associations may be made using this approach – for example, shifts to wetter/cooler climates observed in peat stratigraphy may have had an impact on the groundwater tables and on crop growth in northern Germany around 2700 and 1400 years ago (Barber *et al.* 2004a). However, little can be said about what forms environmentally triggered transitions might take, why certain cultures should be susceptible to them, or – most pertinently – if the proposed relationships can indeed be corroborated.

A causal link cannot be inferred merely by observing correlations between environmental and cultural variables. Considering the near-impossibility of repeating these 'experiments', all that can be said is that one effect occurs alongside the other. Indeed, such associations may be purely coincidental. If one attempts to claim more, the numerous instances where cultures either survived rapid environmental change unscathed or collapsed without the aid of environmental forcing would have to be explained. If causality is to be demonstrated, one must show that environmental change was the critical factor in the culture's collapse. In particular, the models used to explain environment–culture interactions should be considered in more depth. Of course, a model cannot hope to reproduce all the processes and interactions in a particular culture, but a representation of the system's critical components should be feasible. The key question is which model will provide the most plausible representation of the studied collapses. In some scenarios, the interactions between environment and culture will be relatively simple, and consistent relationships between the two may be regarded as evidence of causality. In more complex systems, the relationships will be more non-linear in character, and distinguishing extrinsic and intrinsic forcings near-impossible.

Such models are seldom used in palaeoenvironmental studies, but can easily be adapted from those commonly used by economists and demographers. The following sections outline four generally applicable scenarios for environment–culture interactions – abandonment of marginal land, population decline in marginal land, rapid technological and/or sociocultural advances and system-wide collapse.

A retreat from the margins?

A simple model cannot hope to replicate all the complexities of environment–culture relationships across a civilization, but one basic approach that can provide valuable insights is to treat human populations in ecological terms, with their ranges shifting in response to changing conditions. Such effects should be most apparent in marginal communities, where slight environmental changes would have a major impact on a population's subsistence base. It must first be noted that for human populations marginality is not an intrinsic property of the physical environment; as Brown *et al.* have observed, 'Marginality can only be considered a meaningful idea in relation to a particular economic and social system' (1998, 147). Late Medieval Greenland was an extremely marginal landscape for Norse agropastoralists, but their Inuit contemporaries considered the region exceptionally rich (McGovern 1994). It follows from this that the concept is not a static one, and social and technological changes will modify a culture's perception of a particular landscape. Moreover, socioeconomic and political inequalities mean that individuals in the same community may experience widely differing levels of marginal stress (Young and Simmonds 1996).

Nevertheless, the impact of environmental change on marginal communities can be simulated at a basic level using Malthusian principles; the most elegant model produced in recent years is that of Wood (1998). Wood replaced the carrying capacity constant used in traditional Malthusian models with the more flexible 'demographic saturation' (S_t) – a function of available land, usable resources, productive technology and organization of production. S_t is the only exogenous variable in the model; its behaviour affects the system output but is not controlled by it. When S_t is stable, population fluctuates around a stable point due to second-order interactions between fertility and mortality. These will generate medium-scale, medium-term variations in population; it is only longer-term shifts that are determined by changes in the underlying value of S_t.

The relationship between population and the point of demographic saturation in the system can be expressed graphically (Figure 2). The minimal subsistence requirements θ ($\delta N/\delta t=0$) for the system are expressed as a linear relationship between population and output: those areas above this line have a surplus of resources, those below are in deficit. If unchecked, population will always try to approach the line $\delta N/\delta t=0$: surplus production will allow additional population growth, and shortfalls will lead to population reduction. The level of system output will change in a logistic pattern with increasing levels of population: as the system's demographic saturation point is approached, higher levels of population will bring a progressively lower return per capita.

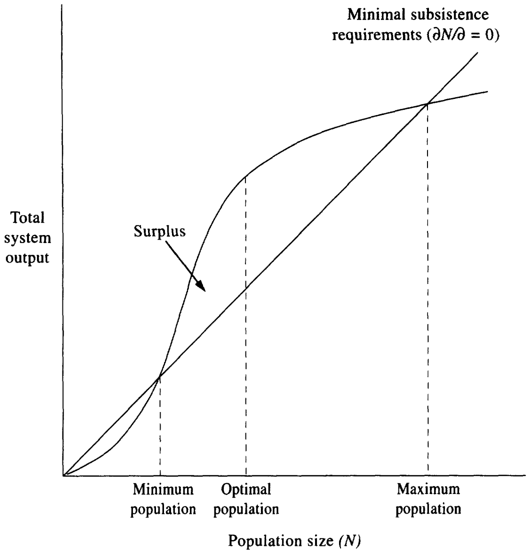

Figure 2 Output and population relationships in pre-industrial societies (after Wood 1998)

The intersection of this curve with $\delta N/\delta t=0$ creates two equilibria, marking the minimum and maximum sustainable populations for the system. The minimum population point is an unstable equilibrium; unless the system is balanced perfectly on this point, positive feedbacks will move population successively further away from it. Conversely, the maximum population point is a stable equilibrium (the sole nontrivial point on the curve), which all neighbouring populations will tend towards. The span between these points, where output exceeds population, is the span of possible populations that the system can support. A third point on the curve, that of optimal population, represents the period of maximum production surplus, and hence the point of maximum well-being (w_t) amongst the population. This is not an equilibrium point; unless additional controls on growth exist, population will always expand towards its maximum limit.

The basic model assumes that S_t remains constant in the system. However, if there is an environmentally driven fall in its level, there will be a corresponding shift in the line of minimal subsistence requirements ($\delta N/\delta t=0$). The points of intersection with the system output curve will change, and the range of possible populations supported will be reduced. This has three potential consequences:

1 If the state of the system moves from below to above the point of maximum population, population will fall (via changes in mortality, fertility or migration) until the new equilibrium has been reached.
2 If the state of the system moves from above to below the point of minimum population, population will fall towards zero.
3 Surplus production within the system will be increasingly small, leading to a reduction in w_t and the system's buffering capabilities.

Small-scale fluctuations in S_t will be a constant feature of any system; left unchecked, these would create a constant succession of demographic changes (cf. Scott *et al.* 1998). Under such circumstances, marginality can be thought of as a probabilistic index of risk vulnerability (Baillie 1998). Any community theoretically can be subject to production crises caused by environmental stress; the distinguishing feature of marginal communities is that these episodes will be far more frequent than in core communities (Van Buren 2001; Adger and Brooks 2003).

Stresses of this type can be combated by buffering subsistence resources within the system (Vasey 2001). A community's buffering capacity may be seen as a parallel of ecological resilience (Adger 2000) – a system's ability to withstand environmental perturbations without a change in its dynamic equilibrium. Communities not yet at the point of demographic saturation will be able to shield themselves from short-term fluctuations by using surplus production (either food or capital) to weather any shortfalls in their subsistence base (Armit 1998). Marginal communities will be at the limit of their subsistence base, with few reserves to fall back on if production is affected. Such defences assume that the magnitude of the crisis will not be such as to overwhelm existing subsistence reserves, and that the environmental perturbations will fluctuate around a stable norm (Schneider *et al.* 2000). If the environmental changes are persistent, such assumptions will be invalid (Yohe 2000; Kelly and Adger 2000) and demographic crisis will result.

A Boserupian footnote

Boserup (1965 1981; cf. Morrison 1996) advanced the idea that environmental stress could act as a trigger for sociocultural development. In her model, as the point of demographic saturation is approached and the level of wellbeing amongst the population decreases, the system comes under increasing pressure

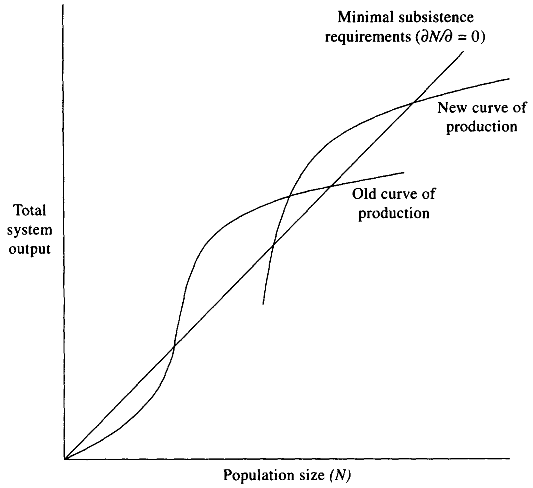

Figure 3 'Boserupian escape clause' – changes in productivity following technological or sociocultural advance (after Wood 1998)

to innovate and reform its production processes. This 'Boserupian escape clause' will transform existing relationships between population and system output, creating a new curve of production with new points of minimal, optimal and maximum population (Figure 3). The community, liberated from its existing constraints, is thus free to grow again until the limits of the new mode of production are reached, whereupon the cycle of innovation begins anew (Dean 2000; Myrdal 2000).

Complexity and collapse

History offers numerous examples of advanced civilizations suddenly collapsing, with their core regions affected as much (if not more so) than their peripheries. Renfrew (1979) identified a number of common aspects in these examples; these included:

1 Increasing sociopolitical dislocation evident in the early stages of the process, followed by a collapse of centralized political and economic organization and the disappearance of the traditional ruling elites.
2 A decline in population, and shift in settlement patterns to dispersed communities and low population densities.
3 A long-term fragmentation of sociopolitical and economic structures, and a transition to communities supporting a lower level of social complexity (cf. Crumley 1993; Bogucki 1996).

The mechanism involved in these cases was clearly distinct from that of low-level subsistence failure in marginal areas. However, an obvious explanation was rarely apparent; although possible triggers might be identified, these were often minor and seemed incapable of causing such disproportionate devastation.

Such events cannot easily be treated in Malthusian terms. However, Brunk (2002) has outlined an alternative hypothesis: these collapses can be interpreted as cascades in self-organizing systems. Self-organization (Bak *et al.* 1987) is a branch of physics which describes the apparently random behaviour of assemblages of cellular automata (components whose behaviour is determined by both their own state and the behaviour of their neighbours). The theory has been applied to phenomena ranging from forest fires to stock market fluctuations, but Bak *et al.* first illustrated it using a model of a sand-grain pile, enlarging over time through the input of extra grains. In a unidimensional system, as the pile enlarges it automatically evolves ('self-organizes') towards a minimally stable stationary state with the slope of the sand-pile at a critical angle of repose. Once this point is reached, the system will stay there. This state is barely stable, and any perturbations will propagate infinitely through the system. If more sand is added, it will slide off, maintaining this same angle; a sand-pile steeper than the critical angle will avalanche until it attains stability at the same point.

If the system is extended to multiple dimensions it immediately becomes more complex. Movements of individual grains will destabilize *multiple* minimally stable neighbours, then their next-nearest neighbours, and so on until an avalanche propagates throughout the system. Any existing minimally stable subsystems will act to transmit disturbances within the larger whole. The avalanching process will continue until a critical number of more-than minimally stable subsystems, unable to propagate the disturbance, have been generated. To an observer without knowledge of the internal structure of the model, the avalanches will appear non-deterministic: they can be caused by the smallest perturbations to the system, and their size and frequency is solely a function of the internal dynamics of the sand-pile. The only regularity in system output is in its fractal scaling, with event frequency and magnitude in an inverse power-law relationship.

Growth in a civilization's sophistication will result in increases in the number and interconnectivity of its economic and sociocultural subsystems (Tainter 1995). These subsystems can be considered the socioeconomic equivalent of the minimally stable subsystems in a sand-pile; as they expand, the civilization will become more and more a 'pure' SOC (self-organizing complexity) system and its outputs more and more fractal (Brunk 2002). Once a disturbance of any size impacts such a system, a 'complexity cascade' (avalanche) will result, disrupting the subsystems. The magnitude of this cascade will be dependent upon the ability of individual system components to pass this disturbance on to their neighbours. A major cascade (civilization collapse) will destroy this complex structure, after which output from the system will revert to a standard stochastic pattern until the growth of the culture's sophistication once again generates SOC output. This cycle of growth and collapse means that long-term cultural progress in complex cultures will only be possible through buffering – which in this paradigm acts to damp the growth of complexity cascades by limiting the connectivity of system components and maintaining as many as possible at a more-than minimal level of stability.

Although such a conclusion seems counter-intuitive, in this scenario complex societies will be more vulnerable to environmental impacts than simple ones (cf. Messerli *et al.* 2000). As the culture develops, individuals will be dependent upon a wider and wider network of subsystems. This growth in sophistication also creates a society that is far more specialized in terms of its environmental 'habitat'; the costs of maintaining the social infrastructure will lead to an increasing degree of social ossification (Phillips 1979; Janssen *et al.* 2003), leaving the community less flexible in its ability to respond to rapid environmental changes.

Conclusions

In summary, one may expect to see four distinct types of social response to environmental change in palaeoenvironmental records:

1 Total collapse of habitation in marginal regions, due to deterioration in the subsistence base leaving local population below minimum sustainable levels.
2 Partial decline of habitation in marginal regions, due to deterioration in the subsistence base leaving local population above maximum sustainable levels.
3 Sudden changes in modes of agricultural production, reflecting Boserupian advances in technological and socioeconomic complexity.
4 Widespread collapse of social organization in both core and peripheral regions, reflecting complexity cascading within a self-organizing system.

The viability of any proposed linkages between environment and culture in contemporary studies will depend on which of these scenarios best describes key processes and relationships in the system.

In the case of marginal settlement abandonment, the sensitivity of such communities to slight environmental perturbations means that their culture–environment relationships can be assumed to be relatively linear. Probabilistic corroboration of such relationships should therefore be feasible provided that data of sufficient spatial and temporal resolution are available. Unfortunately, neat spatial responses to environmental change of the type described by Parry (1974) are rarely noted in palaeoenvironmental records. Episodes of marginal decline (Dumayne-Peaty and Barber 1998; Tinner *et al.* 2003) are typically small scale and subtle, and researchers must be lucky: firstly in detecting them at all and secondly in hoping that their records are reasonably representative of the area studied. This particularly applies in the case of partial declines in settlement: unless cultivation and grazing pressures are almost totally eliminated, there may be very little response to a decline by vegetational and erosional records. All that the palaeoenvironmental researcher can do in such cases is work with poorly represented arable pollen spectra – although there is promise in the use of geochemical indicators of soil erosion (Lomas-Clarke and Barber 2004), especially now that selected multi-elemental analyses can be carried out rapidly and at very high resolution using core-scanning X-ray fluorescence (Barber, Lomas-Clarke and Croudace unpublished results). One should not deny the existence of marginal settlement abandonment; such episodes were doubtless frequent in many pre-industrial cultures. Despite this, such effects are difficult to apprehend using palaeoenvironmental techniques, and most contemporary research has been directed towards more dramatic, large-scale declines.

Uncovering Boserupian effects in palaeoenvironmental records poses problems of a more epistemological nature. Wright (1993) has made a persuasive case for the initial adoption of agriculture by the Natufian culture around 10 000 BC being a response to increasing environmental stress from Younger Dryas aridity in the Middle East. However, there is nothing in the palaeoenvironmental or archaeological records that can conclusively demonstrate such a relationship. During recent centuries, when documentary evidence of new farming techniques exists, it is sometimes possible to demonstrate a simple Boserupian effect of increasing agricultural output (measured pollen-analytically) during the deteriorating climate of the Little Ice Age (Dumayne-Peaty and Barber 1998). However, where detailed historical or anthropological data are absent, claims of causal linkages between environmental stress and sociocultural and technological innovation will be highly speculative.

Most of the cultural collapses that have attracted the attention of Quaternary researchers in the past decade – notably those of the Classic Maya, the Moche, the Egyptian Old Kingdom and the Akkadian empire – were sudden, large-scale events affecting highly organized cultures. All impacted core regions just as much as the peripheries, and all resulted in sudden declines of sociocultural complexity. Such collapses are clearly distinct from marginal subsistence failures; the patterns produced appear more reminiscent of the complexity cascades posited by Brunk (2002). However, if such collapses are the result of cascading in self-organizing systems, any causal relationships with environmental change must be considered questionable.

Self-organizing systems are fundamentally nonlinear in their response to external forcing – an avalanche may as easily be triggered by a pebble as by a boulder. The magnitude of any complexity cascade created by system disturbances is determined by the history of the system (Adams 2001) and the sensitivity of its internal dynamics rather than the size of the forcing. If Brunk's hypothesis is accepted, establishing a causal link between environmental change and cultural collapse will be almost impossible in these systems. Any event of any scale might have acted as the trigger for the collapse – a trigger of relatively minor importance compared to the intrinsic state of the system itself. If environmental forcing is to be inferred, one would have to demonstrate repeatability in these effects, with simultaneous declines taking place in several distinct cultures. For this reason, the case for environmental influence in the widespread cultural declines concurrent with climatic deteriorations at 4200 BP (Peiser 1998; Weiss and Bradley 2001; Barber *et al.* 2004b) and 2700 BP (van Geel *et al.* 1996; Tinner *et al.* 2003; Barber *et al.* 2004a) appears secure. Elsewhere, claims of causality remain conjectural. In studying self-organizing systems, researchers are probably working beyond the limits of what is currently possible using palaeoenvironmental data. To even be sure that self-organized effects exist, one would have to demonstrate a transition in system output from fractal to stochastic scaling at the point of collapse (Dearing and Zolitschka 1999). Such analysis would require time-series data running over several orders of magnitude, a level of temporal resolution beyond virtually all established techniques. In the immediate future, further analysis of such processes is likely to be restricted to the modelling community (Pezzey and Anderies 2003).

In conclusion, multiple scenarios can be defined to show how environmental perturbations can impact economic production and population levels; these scenarios will produce qualitatively distinct patterns in palaeoenvironmental records. Large-scale collapses in sophisticated societies have attracted most of the recent academic interest in this field, yet (paradoxically) it may be hard to establish causal linkages in most of these instances. These collapses may be strongly nonlinear in character, driven by complexity cascades within a self-organizing structure. If so, this invariance between forcing mechanisms and system output means that in such cases one can rarely be certain what the original trigger for the collapse was. Modelling output and high-resolution palaeoenvironmental records may help illuminate this debate in future, but for the present claims of environmental influence upon past cultural transitions should still be treated with a degree of scepticism.

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