How Civilizations Fall: A Theory of Catabolic Collapse

Abstract

The collapse of complex human societies remains poorly understood and current theories fail to model important features of historical examples of collapse.

Relationships among resources, capital, waste, and production form the basis for an ecological model of collapse in which production fails to meet maintenance requirements for existing capital. Societies facing such crises after having depleted essential resources risk catabolic collapse, a self-reinforcing cycle of contraction converting most capital to waste. This model allows key features of historical examples of collapse to be accounted for, and suggests parallels between successional processes in nonhuman ecosystems and collapse phenomena in human societies.

Introduction

The collapse of complex human societies, while a subject of perennial scholarly and popular fascination, remains poorly understood. Tainter (1988), surveying previous attempts to account for the demise of civilizations, noted that most proposed explanations of collapse failed to adequately describe causative mechanisms, and relied either on ad-hoc hypotheses based on details of specific cases or, by contrast, essentially mystical claims (e.g., that civilizations have lifespans like those of individual biological organisms). In another recent survey of collapses in history (Yoffee and Cowgill 1988), contributors proposed widely divergent explanatory models to account for broadly similar processes of decline and breakdown. Tainter (1988) proposed a general theory of collapse, in which complex societies break down when increasing complexity results in negative marginal returns, so that a decrease in sociopolitical complexity yields net benefits to people in the society. This theory has important strengths, and models many features of the breakdown of civilizations, but it fails to account for other factors, especially the temporal dimensions of the process. Tainter defines collapse as a process of marked sociopolitical simplification unfolding on a timescale of "no more than a few decades" (Tainter, 1988, p. 4), replacing an unsustainably high level of complexity with a lower, more sustainable level. Many of the examples he cites, however, fail to fit this description, but occurred over a period of centuries rather than decades (see Table 1) and involved an extended process of progressive disintegration rather than a rapid shift from an unsustainable state to a sustainable one.

The best documented examples of collapse, such as the fall of the western Roman empire, show a distinctive temporal pattern even more difficult to square with Tainter's theory. Thus, during the collapse of Roman power, each of a series of crises led to loss of social complexity and the establishment of temporary stability at a less complex level. Each such level then proved to be unsustainable in turn, and was followed by a further crisis and loss of complexity (Gibbon 1776-88; Tainter, 1988; Grant, 1990). In many regions, furthermore, the sociopolitical complexity remaining after the empire’s final disintegration was far below the level that had existed in the same area prior to its inclusion in the Imperial system. Thus Britain in the late pre-Roman Iron Age, for example, had achieved a stable and flourishing agricultural society with nascent urban centers and international trade connections, while the same area remained depopulated, impoverished, and politically chaotic for centuries following the collapse of imperial authority (Snyder 2003).

An alternative model based on perspectives from human ecology offers a more effective way to understand the collapse process. This conceptual model, the theory of catabolic collapse, explains the breakdown of complex societies as the result of a self-reinforcing cycle of decline driven by interactions among resources, capital, production, and waste. Previous work on the human ecology of past civilizations (e.g., Hughes, 1975; Sanders et al., 1979; Ponting, 1992; Elvin, 1993; Webster, 2002) and attempts to project the impact of ecological factors on present societies (e.g., Catton, 1980; Gever et al., 1986; Meadows et al., 1992; Duncan, 1993; Heinberg, 2002) have yielded data and analytical tools from which a general theory of the collapse of complex societies may be developed. This will be attempted here.

The Human Ecology of Collapse

At the highest level of abstraction, any human society includes four core elements. Resources (R) are naturally occurring factors in the environment which can be exploited by a particular society, but have not yet been extracted and incorporated into the society’s flows of energy and material. Resources include material resources such as iron ore not yet mined and naturally occurring soil fertility that has not yet been exhausted by the society’s agricultural methods, human resources such as people not yet included in the workforce, and information resources such as scientific discoveries which can be made by the society's methods of research but have not yet been made. While the resources available to any society, even the simplest, are numerous, complex, and changing, this conceptual model treats resources as a single variable. This radical oversimplification is acceptable solely because it allows certain large-scale patterns to be seen clearly, and permits one model to be applied to the widest possible range of societies. Capital (C) consists of all factors from whatever source that have been incorporated into the society’s flows of energy and material but are capable of further use. Capital includes physical capital such as food, fields, tools, and buildings; human capital such as laborers and scientists; social capital such as social hierarchies and economic systems; and information capital such as technical knowledge. While a market system is a form of social capital, and currency and coinage are forms of physical capital, it should be noted that money as such is a mechanism for allocating and controlling capital rather than a form of capital in its own right. While the capital stocks of every society are diverse, complex, and changing, again, for the sake of exposition, this model treats all capital as a single variable.

Waste (W) consists of all factors that have been incorporated into the society’s flows of energy and material, and exploited to the point that they are incapable of further use. Materials used or converted into pollutants, tools and laborers at the end of their useful lives, and information garbled or lost, all become waste. All waste is treated as a single variable for the purpose of this conceptual model.

Production (P) is the process by which existing capital and resources are combined to create new capital and waste. The quality and quantity of new capital created by production are functions of the resources and existing capital used in production. Resources and existing capital may be substituted for one another in production, but the relation between the two is nonlinear and complete substitution is impossible. As the use of resources approaches zero, in particular, maintaining any given level of production requires exponential increases in the use of existing capital, due to the effect of decreasing marginal return (Clark and Haswell, 1966; Wilkinson, 1973; Tainter, 1988). For the purpose of this model, all production is treated as a single variable.

In any human society, resources and capital enter the production process, and new capital and waste leave it. Capital is also subject to waste outside production – uneaten food suffers spoilage, for example, and unemployed laborers still grow old and die. Thus, maintenance of a steady state requires new capital from production to equal waste from production and capital:

$C(p) = W(p) + W(c)$ --> steady state (1)

where C(p) is new capital produced, W(p) is existing capital converted to waste in the production of new capital, and W(c) is existing capital converted to waste outside of production. The sum of W(p) and W(c) is M(p), maintenance production, the level of production necessary to maintain capital stocks at existing levels. Thus Equation 1 can be more simply put:

$C(p) = M(p)$ --> steady state (2)

Societies which move from a steady state into a state of expansion produce more than necessary to maintain existing capital stocks:

$C(p) > M(p)$ --> expansion (3)

In the absence of effective limits to growth, once started, this expansion becomes a self-reinforcing process, because additional capital can be brought into the production process, where it generates yet more new capital, which can be brought into the production process in turn. The westward expansion of the United States in the 19th century offers a well-documented example; in a resource-rich environment, increases in human capital through immigration and increases in information capital through development of new agricultural technologies increased production, driving increases in physical capital through geographical expansion, settling of arable land, manufacturing, etc., which increased production again and drove further increases across the spectrum of capital (Billington 1982).

This process may be called an anabolic cycle. The self-reinforcing aspect of an anabolic cycle is limited by two factors that tend to limit increases in C(p). First, resources may not be sufficient to maintain indefinite expansion. Here the use of “resources” as a single variable must be set aside briefly. Each resource has a replenishment rate, r(R), the rate at which new stocks of the resource become available to the society. For any given resource and society at any given time, $r(R)$ is a weighted product of the rates of natural production, new discovery of existing deposits, and development of alternative resources capable of filling the same role in production. Over time, since discovery and the development of replacements are both subject to decreasing marginal returns (Clark and Haswell, 1966; Wilkinson, 1973; Tainter, 1988), $r(R)$ approaches asymptotically the combined rate at which the original resource and replacements are created by natural processes.

Each resource also has a rate of use by the society, $d(R)$, and the relationship between $d(R)$ and $r(R)$ forms a core element in the model. Resources used faster than their replenishment rate, $d(R)/r(R) >1$, become depleted; a depleted resource must be replaced by existing capital to maintain production, and the demand for capital increases exponentially as depletion continues. Thus, unless all of a society's necessary resources have an unlimited replenishment rate, $C(p)$ cannot increase indefinitely because $d(R)$ will eventually exceed $r(R)$, leading to depletion and exponential increases in capital required to maintain $C(p)$ at any given level.

Liebig's law of the minimum suggests that for any given society, the essential resource with the highest value for $d(R)/r(R)$ may be used as a working value of

$d(R)/r(R)$ for resources as a whole.

Resource depletion is thus one of the two factors that tends to overcome the momentum of an anabolic cycle. The second is inherent in the relationship between capital and waste. As capital stocks increase,

$M(p)$ rises, since $W(c)$

rises proportionally to total capital; more capital requires more maintenance and replacement. $M(p)$ also rises as $C(p)$ rises, since increased production requires increased use of capital and thus increased $W(p)$, or conversion of capital to waste in the production process. All other factors being equal, the effect of $W(c)$ is to make $M(p)$ rise faster than $C(p)$, since not all capital is involved in production at any given time, but all capital is constantly subject to conversion to waste. Increased $C(p)$ relative to $M(p)$ can be generated by decreasing capital stocks to decrease $W(c)$; by slowing the conversion of capital to waste to decrease $W(c)$ and/or $W(p)$; by increasing the fraction of capital involved in production, to increase $C(p)$; or by increasing the intake of resources for production, thus increasing $C(p)$. If these are not done, or prove insufficient to meet the needs of the situation, $M(p)$ will rise to equal or exceed $C(p)$ and bring the anabolic cycle to a halt.

Broadly speaking, a society facing the end of an anabolic cycle faces a choice between two strategies. One strategy is to move toward a steady state in which $C(p) = M(p)$, and $d(R) = r(R)$ for every economically significant resource. Barring the presence of environmental limits, this requires social controls to keep capital stocks down to a level at which maintenance costs can be met from current production, and maintain intake of resources at or below replenishment rates. This can require difficult collective choices, but as long as resource availability remains stable, controls on capital growth stay in place, and the society escapes major exogenous crises, this strategy can be pursued indefinitely.

The alternative is to attempt to prolong the anabolic cycle through efforts to accelerate intake of resources through military conquest, new technology, or other means. Since increasing production increases W(p) and increasing capital stocks lead to increased W(c), however, such efforts drive further increases in M(p). A society that attempts to maintain an anabolic cycle indefinitely must therefore expand its use of resources at an ever-increasing rate to keep C(p) from dropping below M(p).

Since this exacerbates problems with depletion, as discussed above, this strategy may prove counterproductive. If the attempt to achieve a steady state fails, or if efforts at increasing resource intake fall irrevocably behind rising M(p), a society enters a state of contraction, in which production of new capital does not make up for losses due to waste:

C(p) < M(p) --> contraction (4)

The process of contraction takes two general forms, depending on the replenishment rate of resources used by the society. A society that uses resources at or below replenishment rate (d(R)/r(R) = 1), when production of new capital falls short of maintenance needs, enters a maintenance crisis in which capital of all kinds cannot be maintained and is converted to waste: physical capital is destroyed or spoiled, human populations decline in number, large-scale social organizations disintegrate into smaller and more economical forms, and information is lost.

Because resources are not depleted, maintenance crises are generally self-limiting. As capital is lost, M(p) declines steeply, while declines in C(p) due to capital loss are cushioned to some extent by the steady supply of resources. This allows a return to a steady state or the start of a new anabolic cycle once the conversion of capital to waste brings M(p) back below C(p).

A society that uses resources beyond replenishment rate (d(R)/r(R) > 1), when production of new capital falls short of maintenance needs, risks a depletion crisis in which key features of a maintenance crisis are amplified by the impact of depletion on production. As M(p) exceeds C(p) and capital can no longer be maintained, it is converted to waste and unavailable for use. Since depletion requires progressively greater investments of capital in production, the loss of capital affects production more seriously than in an equivalent maintenance crisis. Meanwhile further production, even at a diminished rate, requires further use of depleted resources, exacerbating the impact of depletion and the need for increased capital to maintain production. With demand for capital rising as the supply of capital falls, C(p) tends to decrease faster than M(p) and perpetuate the crisis. The result is a catabolic cycle, a self-reinforcing process in which C(p) stays below M(p) while both decline. Catabolic cycles may occur in maintenance crises if the gap between C(p) and M(p) is large enough, but tend to be self-limiting in such cases. In depletion crises, by contrast, catabolic cycles can proceed to catabolic collapse, in which C(p) approaches zero and most of a society’s capital is converted to waste.

A society in a depletion crisis does not inevitably proceed to catabolic collapse. If depletion is limited, so that decreased demand for resources as a consequence of diminished production brings d(R) back below r(R), the accelerated fall in C(p) may not take place and the crisis may play out much like a maintenance crisis. If the gap between C(p) and M(p) is modest, nonproductive capital may be diverted to production to raise C(p) or preferentially converted to waste to bring down M(p), forcing C(p) and M(p) temporarily into balance in order to buy time for a transition to a steady state. A society in which depletion is advanced and M(p) rapidly increasing relative to C(p), though, may not be able to escape catabolic collapse even if such steps are taken. Cultural and political factors may also make efforts to avoid catabolic collapse difficult to accomplish, or indeed to contemplate.

Testing the Model

These two forms of collapse, maintenance crisis leading to recovery and depletion crisis leading to catabolic collapse, are to some extent ideal types, and form two ends of a complex spectrum of societal breakdown. Most historical examples of collapse fall somewhere in the range between. The limitations of the abstract and extremely simplified model on which the theory is based should also be kept firmly in mind when attempting to apply it to past or present examples. Still, a survey of historical examples shows that many of these have features which support the model proposed in this paper. Closest to the maintenance-crisis end of the spectrum are tribal societies such as the Kachin of Burma. Kachin communities cycle up and down from relatively decentralized (gumlao) to relatively centralized (shan) social forms without significant losses of physical, human, or information capital. In this case anabolic cycles lead to the growth of organizational capital in the form of relatively centralized social forms, but the maintenance costs of this organizational capital prove to be unsustainable, leading to maintenance crises, loss of social capital, and the restoration of less resource- and capital-intensive social forms (Leach, 1954).

Essentially the same process on a larger and more destructive scale characterizes the history of imperial China from the tenth century BCE to the end of the nineteenth century CE.. Efficient cereal agriculture and local market economies provided the foundation for a series of anabolic cycles resulting in the establishment of centralized imperial dynastic states (Gates, 1996; Di Cosmo, 1999). These anabolic cycles drove increases in population, public works such as canals and flood control projects, and sociopolitical organization, which proved unsustainable over the long term. As maintenance costs exceeded the imperial government's resources, repeated maintenance crises led to the breakup of national unity, invasion by neighboring peoples, loss of infrastructure and steep declines in population (Ho, 1970; Di Cosmo, 1999). Iimperial China's resource base had a relatively high replenishment rate, due largely to the long-term sustainability of traditional Chinese agriculture and the use of human and animal muscle as the primary energy sources, and any significant depletion was made good once population levels dropped (Elvin, 1993). Though resource depletion played a limited role, the maintenance crises of imperial China were self-limiting and resulted in contraction to more modest levels of population and sociopolitical organization, rather than the total collapse of the society.

The collapse of the western Roman Empire, by contrast, was a catabolic collapse driven by a combined maintenance and resource crisis. While the ancient Mediterranean world, like imperial China, was primarily dependent on readily replenished resources, the Empire itself was the product of an anabolic cycle fueled by easily depleted resources and driven by Roman military superiority. Beginning in the third century BCE, Roman expansion transformed the capital of other societies into resources for Rome as country after country was conquered and stripped of movable wealth. Each new conquest increased the Roman resource base and helped pay for further conquests. After the first century CE, though, further expansion failed to pay its own costs. All remaining peoples within the reach of Rome were either barbarian tribes with little wealth, such as the Germans, or rival empires capable of defending themselves, such as the Parthians (Jones 1974). Without income from new conquests, the maintenance costs of empire proved unsustainable, and a catabolic cycle followed rapidly. The first major breakdown in the imperial system came in 166 CE, and further crises followed until the Western empire ceased to exist in 476 CE (Grant 1990, Grant 1999).

The Roman collapse has an instructive feature which offers further support to the model presented here. In 297 the emperor Diocletian divided the empire into western and eastern halves. Coordination between them waned, and by the death of Theodosius I in 395, the two halves of the empire were effectively independent states. Since the western empire produced 1/3 the revenues of the eastern empire, but had more than twice as much northern frontier to defend against barbarian encroachments, this placed most of the original empire's vulnerabilities in one half and most of its remaining resources in the other. In terms of the catabolic collapse model, the eastern Empire allowed massive quantities of relatively unproductive, high-maintenance capital to be converted to waste, bringing its M(p) below its remaining C(p) and breaking out of the catabolic cycle. The eastern empire's territory decreased further with the Muslim conquests of the seventh and eighth centuries CE; while this was involuntary the effects were the same.

Successfully shifting to a level of organization that could be supported sustainably by trade and agriculture within a more manageable territory, the eastern Empire survived for nearly a millennium longer than its western twin (Bury 1923). Near the depletion crisis end of the spectrum is the collapse of the Lowland Classic Maya in the eighth, ninth, and tenth centuries of the Common Era. The most widely accepted model of the Maya collapse holds on demographic and paleoecological evidence that Maya populations grew to a level that could not be indefinitely supported by Mayan agricultural practices on the nutrient-poor laterite soils of the Yucatan lowlands. In terms of the present model, the key resource of soil fertility was used at a rate exceeding its replenishment rate, and suffered severe depletion as a result. Mayan polities also invested a large proportion of C(p) in monumental building programs, which raised maintenance costs but could not be readily used for production, and maintained these programs up to the beginning of the Terminal Classic period. The result was a “rolling collapse” over two centuries, from c. 750 CE to c. 950 CE, in which Lowland Maya populations declined precipitously and scores of urban centers were abandoned to the jungle (Willey and Shimkin 1973, Lowe 1985, Webster 2002).

The Lowland Classic Maya collapse is particularly suggestive in that it appears to have been preceded by at least two previous breakdowns. Preclassic sites such as El Mirador and Becan show many of the same artistic and cultural elements as Classic Maya urban centers, but were abandoned in a poorly documented earlier collapse around 150 CE (Webster 2002). A second episode, the so-called Hiatus between the Early Classic and Late Classic periods (500-600 CE), saw sharp declines in monumental building and evidence for political decentralization (Willey 1974).

Whether these events were maintenance crises preceding the final resource crisis of the Terminal Classic, or whether some other explanation is called for, is difficult to determine from the available evidence.

Features of comparative sociology outside the realm of collapse processes also offer support to the catabolic collapse model. One implication of the model is that societies which persist over extended periods will tend to have social mechanisms for limiting the growth of capital, and thus artificially lowering M(p) below C(p). Such mechanisms do in fact exist in a wide range of societies. Among the most common are systems in which modest amounts of unproductive capital are regularly converted to waste. Examples include aspects of the potlatch economy among Native Americans of northwest North America (Kotschar, 1950; Rosman, 1971; Beck, 1993) and the ritual deposition of prestige metalwork in lakes and rivers by Bronze and Iron Age peoples in much of western Europe (Bradley, 1990; Randsborg, 1995).

Such systems have been interpreted in many ways (Michaelson, 1979), but in terms of the model presented here, one of their functions is to divert some of C(p) away from capital stocks requiring maintenance, thus artificially lowering W(c) and make a catabolic cycle less likely. Such practices clearly have many other meanings and functions within societies. ***Nor does this interpretation require any awareness within societies that systems of capital destruction prevent catabolic cycles. Rather, if such systems make catabolic collapse less likely, cultures that adopt such systems for other reasons would be more likely to survive over the long term and to pass on such cultural*** elements to neighboring or successor societies.

Conclusion: Collapse as a Succession Process

Even within the social sciences, the process by which complex societies give way to smaller and simpler ones has often been presented in language drawn from literary tragedy, as though the loss of sociocultural complexity necessarily warranted a negative value judgment. This is understandable, since the collapse of civilizations often involves catastrophic human mortality and the loss of priceless cultural treasures, but like any value judgment it can obscure important features of the matter at hand.

A less problematic approach to the phenomenon of collapse derives from the idea of succession, a basic concept in the ecology of nonhuman organisms. Succession describes the process by which an area not yet occupied by living things is colonized by a variety of biotic assemblages, called seres, each replacing a prior sere and then being replaced by a later, until the process concludes with a stable, self-perpetuating climax community (Odum 1969).

One feature of succession in many different environments is a difference in resource use between earlier and later seres. Species characteristic of earlier seral stages tend to maximize control of resources and production of biomass per unit time, even at the cost of inefficiency; thus, such species tend to maximize production and distribution of offspring even when this means the great majority of offspring fail to reach reproductive maturity. Species typical of later seres, by contrast, tend to maximize the efficiency of their resource use, even at the cost of limits to biomass production and the distribution of individual organisms; thus these species tend to maximize energy investment in individual offspring even when this means that offspring are few and the species fails to occupy all available niche spaces.

Species of the first type, or R-selected species, have specialized to flourish opportunistically in disturbed environments, while those of the second type, or K-selected species, have specialized to form stable biotic communities that change only with shifts in the broader environment (Odum 1969).

Human societies and nonhuman species cannot be equated in a simplistic manner, but the radical differences in subsistence and production strategies among human societies allow them to be compared to distinct biotic groups in certain contexts. Human societies enter into common ecological relationships such as symbiosis, commensality, parasitism, predation, and competitive exclusion with other societies.

Thus, processes by which human societies are replaced by others may be usefully compared to succession to see if common features emerge. The model of catabolic collapse suggests one such common feature.

As outlined above, societies differ in their response to changes in resource availability and maintenance costs. The spectrum of response ranges from adjustment to a steady state, through a history of repeated maintenance crises and partial breakdowns followed by recoveries, to severe depletion crisis and total collapse. These differences, according to the model presented here, unfold from differing relationships among resources, capital, production, and waste, especially the relationships between capital production and maintenance, C(p)/M(p), and between use and replenishment rates of resources, d(R)/r(R).

These parallel differences between R-selected and K-selected nonhuman species. A society that maximizes its production of capital, like an R-selected species, prospers in an environment with substantial uncaptured resources but falters once these are exhausted. Its successors are likely to be societies that, like selected species, use key resources more sustainably at the cost of decreased production of capital. Nonhuman climax communities also typically display a higher diversity of species, but a lower population per species, than earlier seral stages, and produce notably lower volumes of biomass per unit time (Odum 1969).

Broadly similar changes often distinguish pre-collapse and post collapse societies. Thus, the collapse of the western Roman Empire, for example, could be seen as a succession process in which one seral stage, dominated by a single sociopolitical “species” that maximized capital production at the cost of inefficiency, was replaced by a more diverse community of societies, consisting of many less populous “species” better adapted to their own local conditions, and producing capital at lower but more sustainable rates. Analyses that portray this transformation as pure tragedy miss important aspects, since the Roman collapse enabled other societies to emerge from Rome’s shadow, and launched major cultural initiatives such as vernacular literatures in the ancestors of today’s Celtic, Germanic, and Romance languages (Wiseman 1997). As with any succession process, there were gainers as well as losers. If a lapse into fantasy may be excused, were nonhuman biota literate and interested in their past, a history of lake eutrophication written by meadow grasses would differ sharply from one written by fish.

Since humans have capacities for change that most species lack, the same human individuals can change from fish to grass, so to speak, composing an “R-selected” production-maximizing society at one time and its “K-selected” sustainability-maximizing replacement at a later time. The example of the Kachin cited above shows that this is not merely a theoretical possibility. However, as other cited examples and the general evidence of history suggest, such a change is not inevitable. The possibility of maintenance crisis needs to be considered whenever a society shows signs of being unable to maintain its existing capital, and the possibility of depletion crisis followed by catabolic collapse cannot be excluded whenever capital production depends on the use of resources at rates significantly above their rate of replacement. Such assessments of past and present societies, in order to achieve a high degree of analytic or predictive value, require careful quantitative analysis of a sort this paper has not attempted. Since each element in the conceptual model presented here stands for a diverse and constantly changing set of variables, such analysis offers significant challenges, and in many historical examples it may be impossible to go beyond proxy measurements of uncertain value for crucial variables. However, general patterns corresponding to the catabolic collapse model may be easier to extract from incomplete data. Any society that displays broad increases in most measures of capital production coupled with signs of serious depletion of key resources, in particular, may be considered a potential candidate for catabolic collapse.

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Table 1: Timescales of collapse for selected civilizations (all dates from Tainter 1988)

Civilization	Onset of collapse	Time to collapse
Minoan Crete	c. 1500 BCE	c. 300 years
Mycenean Greece	c.1200 BCE	c. 150 years
Hittite Empire	c. 120 BCE	c. 100 years
Western Chou empire	934 BCE	163 years
Western Roman Empire	166 CE	310 years
Medieval Mesopotamia	c.650 CE	c. 550 years
Lowland Classic Maya	c.750 CE	c. 150 years