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In the cosmology of Western industrial societies, "progress" results from human creativity enacted in facilitating circumstances. In human history, creativity leading to progress was supposedly enabled by the development of agriculture, which provided surplus energy and freed people from needing to spend full time in subsistence pursuits. Applying this belief to the matter of sustainability today leads to the supposition that we can voluntarily reduce resource use by choosing a simpler way of life with lower consumption. Recent research suggests that these beliefs are deeply inaccurate. Humans develop complex behaviors and institutions to solve problems. Complexity and problem solving carry costs and require resources. Rather than emerging from surplus energy, cultural complexity often precedes the availability of energy and compels increases in its production. This suggests that, with major problems converging in coming decades, voluntary reductions in resource consumption may not be feasible. Future sustainability will require continued high levels of energy consumption.

Keywords collapse, complexity, cultural evolution, resources, sustainability

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I. RESOURCES AND CULTURAL COMPLEXITY

Few questions of the social sciences have been more enduring than how today's complex societies evolved from the small foraging bands of our ancestors. While this question might seem to be of narrow academic interest, it has in fact implications of the highest importance for anticipating our future. Our understanding of sustainability and the human future depends to a surprising degree on our understanding of the human past. The emphasis of this essay is to show that some of the conventional understandings of cultural evolution are untenable, as are assumptions about sustainability that follow from them. A new framework is presented that will more realistically delineate the future connection of resources to sustainability.

Complexity is a popular topic today, and there are various conceptions of it. One can find, in various literatures, references to physical complexity, ecological complexity, algorithmic complexity, computational complexity, social complexity, and probably other varieties as well. Complexity can be specified, irreducible, or unruly. Complexity can occur within a system, or by embedding different levels of systems. The concept used here derives from Anthropology, and specifically from this discipline's focus on the ancestry of today's complex society.

The focus is cultural complexity, encompassing all of the social, ideological, behavioral, economic, and technological elements that comprise a cultural system. Cultural complexity consists of differentiation in structure and variation in organization. As human societies have evolved they have developed more differentiated structures. Julian Steward, for example, once noted the difference between the 3,000 to 6,000 cultural elements early anthropologists documented for native populations of western North America, and the more than 500,000 artifact types that U.S. military forces landed at Casablanca in World War II (1955). Similarly, hunter-gatherer societies incorporate no more than a few dozen distinct social personalities, while modern European censuses recognize 10,000 to 20,000 unique occupational roles, and industrial societies may contain overall more than 1,000,000 different kinds of social personalities (McGuire, 1983).

But structural differentiation alone does not equal complexity. The behavior of structural elements (such as roles and institutions) must be constrained for the elements to function as a system. This constraint is provided through organization. Organization limits and channels behavior, making the activities of behavioral elements predictable. Organization gives a system coherence. For example, although the materiél that U.S. forces took to Casablanca was highly differentiated (500,000 artifact-types, as noted by Steward), it was not fully a complex system. The materiél was loaded on the transport ships in a haphazard fashion (Atkinson, 2002). The results were predictable. As Atkinson describes, "Guns arrived on the beach with no gunsights; guns arrived with no ammunition; guns arrived with no gunners" (2002). About 260,000 tons of materiél, enough for 1.5 months of fighting, simply disappeared in Britain. There was a clear lack of organization, which is what differentiated structures require to form a system. Without organization (normally provided by "combat loading"), the impressive lot of materiél was merely an assemblage. In human history, complex societies evolved through increasingly differentiated structures that were integrated by increasing organization.

Cultural complexity is deeply embedded in our contemporary self-image, although colloquially we do not know it by that term. Rather, cultural complexity is known in popular discourse by the more common term "civilization," which we believe our ancestors achieved through the phenomenon called "progress." The concepts of civilization and progress have a status in the cosmology of industrial societies that amounts to what anthropologists call "ancestor myths." Ancestor myths validate a contemporary social order by presenting it as a natural and sometimes heroic progression from earlier times. Just as Pueblo Indians tell how their ancestors emerged from the underworld and California Indians tell how the trickster Coyote changed the world, so in industrial societies we tell how our ancestors discovered fire, agriculture, and the wheel, and conquered untamed continents.

Social scientists label this a "progressivist" view of cultural evolution. It is based on the supposition that cultural complexity is intentional, that it emerged merely through the inventiveness of our ancestors, the outcome constituting progress. Progressivism is the dominant ideology of free-market societies today. But inventiveness is not a sufficient explanation for cultural complexity. It is not a constant in human history. Rather, inventiveness must be enacted in facilitating circumstances. What were those circumstances? Prehistorians once thought they had the answer: The discovery of agriculture gave our ancestors surplus food and, comcomitantly, free time to invent urbanism and the things that comprise "civilization" (e.g., Childe, 1944). Through the mechanism of agriculture, plants figure centrally in the progressivist view of cultural evolution. Vere Gordon Childe may be the prehistorian most influential in propagating this argument. He wrote:

> On the basis of the neolithic economy further advances could be made...in that farmers produced more than was needed for domestic consumption to support new classes...in secondary industry, trade, administration or the worship of gods (1944).

Eventually, in this line of reasoning, progress facilitated by agricultural surpluses led to the emergence of cities, artisans, priesthoods, kings, aristocracies, and all of the other features of what are called archaic states (Childe, 1944).

At first glance Childe's argument appears plausible. Its seeming reasonableness, though, stems from its logical consistency with the progressivist ideology of industrial societies. Give humans the resources to invent cultural complexity and axiomatically, it is believed, they will. Prehistorians, after all, are themselves socialized members of industrial societies. They are raised to believe the values and ideologies of their societies, so it is natural that they internalize a progressivist view. This unsurprisingly influences their interpretations of the past. Archaeology emerged as a pastime of the middle and upper classes, and early frameworks for arranging the past—ages of stone, bronze, and iron, for example—reflect a belief in material progress. Consider the implied progressivism of the titles of some prominent books:

- *Man Makes Himself* (Childe, 1951),
- *Man's Rise to Civilization: The Cultural Ascent of the Indians of North America* (Farb, 1978),
- *The Ascent of Man* (Bronowski, 1973).

While these are older works, the progressivist view persists to this day. It is exemplified prominently in the recent popular books of Jared Diamond (1997, 2005; see Tainter, 2005).

II. CHALLENGING THE PROGRESSIVIST VIEW

The progressivist view posits a specific relationship between resources (including plants) and civilization. It is that complexity emerges because it can, and that the factor facilitating this is surplus energy arising from such innovations as fire, agriculture, and the wheel. Surplus energy precedes complexity and allows it to emerge. Unfortunately for popular cosmology there are significant reasons to doubt the extent to which surplus energy has driven cultural evolution.

One strand of thought that challenges progressivism emerged in the eighteenth century with the works of Wallace (1761) and Malthus (1798). Malthus was influenced by Wallace, who argued that progress would undermine itself by filling the world with people. Stimulated by Malthus, Jevons (1866) worried that Britain's industrial development and global leadership would outrun the supply of coal. Jevons argued that as technological improvements increase the efficiency with which a resource is used, total consumption of that resource may increase rather than decrease. This became known as the Jevons Paradox or Rebound Effect (Polimeni *et al*., 2008). Malthus also set the stage for contemporary theorists of consumption overshoot, such as Erlich (1968) and Catton (1980).

Boulding derived from Malthus's essay on population three theorems. The first is called the Dismal Theorem:

> If the only ultimate check on the growth of population is misery, then the population will grow until it is miserable enough to stop its growth (Boulding, 1959).

Theorem two is the Utterly Dismal Theorem, and it directly challenges the progressivist view:

> Any technical *improvement* can only relieve misery for a while, for as long as misery is the only check on population, the improvement will enable population to grow, and will soon enable *more* people to live in misery than before. The final result of improvements, therefore, is to increase the equilibrium population, which is to increase the sum total of human misery (Boulding, 1959 [emphases in original]).

Boulding's third theorem is called the moderately cheerful form of the Dismal Theorem:

> If something else, other than misery and starvation, can be found which will keep a prosperous population in check, the population does not have to grow until it is miserable and starves, and can be stably prosperous (Boulding, 1959).

Boulding observed that how to implement the Cheerful Theorem "is a problem which has so far produced no wholly satisfactory solution" (1959).

The implication of this strain of thought is that humans have rarely had surplus energy. When we have had surplus resources, we have not had them regularly or in abundance for long. Surpluses have been dissipated quickly by growth in consumption. Since humans have rarely had surpluses, the availability of energy cannot be the primary driver of cultural evolution.

Beyond a Malthusian view, there is another strand of criticism that undermines progressivism. It is that complexity costs. In any living system, increased complexity carries a metabolic cost. In non-human species this cost is a straightforward matter of additional calories that must be found and consumed. Among humans the cost is calculated in such currencies as resources, effort, time, or money, or by more subtle matters such as annoyance. While humans find complexity appealing in spheres such as art, music, or architecture, we usually prefer that someone else pay the cost. We are averse to complexity when it unalterably increases the cost of daily life without a clear benefit to the individual or household. Before the development of fossil fuels, increasing the complexity and costliness of a society meant that *people* worked harder.

The development of complexity is thus a paradox of human history. Over the past 12,000 years, we have developed technologies, economies, and social institutions that cost more labor, time, money, energy, and annoyance, and that go against our aversion to such costs. We have progressively adopted ways of life that impose increasing costs on both societies and individuals, and that contravene some of our deepest inclinations. Why, then, did human societies ever become more complex?

At least part of the answer is that complexity is a basic problem-solving tool. Confronted with problems, we often respond by developing more complex technologies, establishing new institutions, adding more specialists or bureaucratic levels to an institution, increasing organization or regulation, or gathering and processing more information. Such increases in complexity work in part because they can be implemented rapidly, and typically build on what was developed before. While we usually prefer not to bear the cost of complexity, our problem-solving efforts are powerful complexity generators. All that is needed for growth of complexity is a problem that requires it. Since problems continually arise, there is persistent pressure for complexity to increase (Tainter 1988, 1996, 2000, 2006).

Growth of complexity is well illustrated in the response to the attacks on the United States of September 11, 2001. In the aftermath, steps taken to prevent future similar attacks focused on creating new government agencies, such as the Transportation Security Administration and the Department of Homeland Security, consolidating existing functions into some of the new agencies, and increasing control over realms of behavior from which a threat might arise. In other words, our first response was to complexify—to diversify structure and function, and to increase organization or control. The report of the government commission convened to investigate the attacks (colloquially called the 9/11 Commission) recommended steps to prevent future attacks. The recommended actions amount, in effect, to more complexity, requiring more costs in the form of resources, time, or annoyance (9/11 Commission, 2004).

The costliness of complexity is not a mere annoyance or inconvenience. It conditions the long-term success or failure of problem-solving efforts. Complexity can be viewed as an economic function. Societies and institutions invest in problem solving, undertaking costs and expecting benefits in return. In any system of problem solving, early efforts tend to be simple and cost-effective. That is, they work and give high returns per unit of effort. This is a normal economic process: humans always tend to pluck the lowest fruit, going to higher branches only when those lower no longer hold fruit. In problem-solving systems, inexpensive solutions are adopted before more complex and expensive ones. In the history of human food-gathering

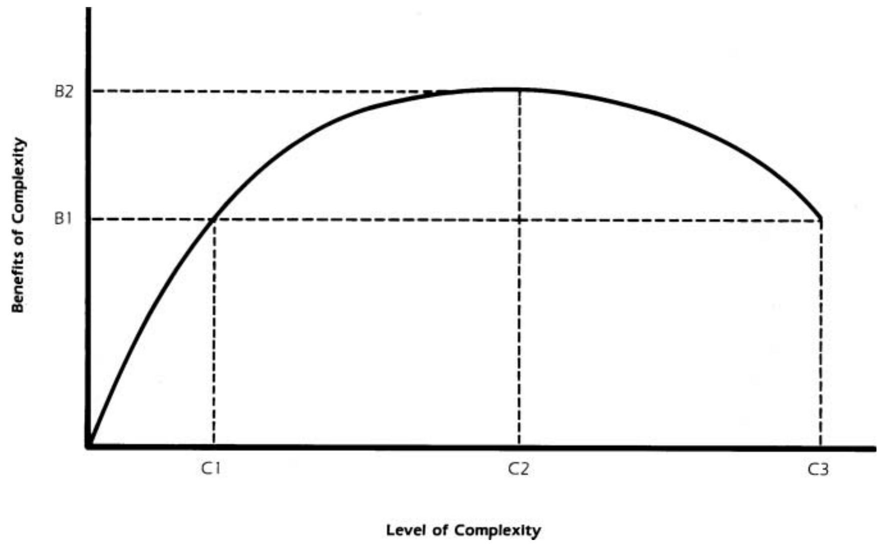

FIG. 1. The marginal productivity of increasing complexity. At a point such as B1, C3, the costs of complexity exceed the benefits, and complexity is a disadvantageous approach to problem solving.

and production, for example, labor-sparing hunting and gathering gave way to more labor-intensive agriculture, which in some places has been replaced by industrial agriculture that consumes more energy than it produces (Boserup, 1965; Clark and Haswell, 1966; Cohen, 1977). We produce minerals and energy whenever possible from the most economic sources. Our societies have changed from egalitarian relations, economic reciprocity, *ad hoc* leadership, and generalized roles to social and economic differentiation, specialization, inequality, and full-time leadership. These characteristics are the essence of complexity, and they increase the costliness of any society.

As high-return solutions are progressively implemented, only more costly solutions remain. As the highest-return ways to produce resources, process information, and organize society are applied, continuing problems must be addressed in ways that are more costly and less cost-effective. As the costs of solving problems grow, the point is reached where further investments in complexity do not give a proportionate return. Increments of investment in complexity begin to yield smaller and smaller increments of return. The *marginal* return (that is, the return per extra unit of investment) starts to decline (Figure 1).

This is the long-term challenge faced by problem-solving institutions: diminishing returns to complexity. If allowed to proceed unchecked, eventually it brings ineffective problem solving and even economic stagnation. A prolonged period of diminishing returns to complexity is a major part of what makes problem solving ineffective and societies or institutions unsustainable (Tainter, 1988, 1999, 2000, 2006).

In the progressivist view, surplus energy precedes and facilitates the evolution of complexity. Certainly this is sometimes true: There have been occasions when humans adopted energy sources of such great potential that, with further development and positive feedback, there followed great expansions in the numbers of humans and the wealth and complexity of societies. These occasions have, however, been rare, so much so that we designate them with terms signifying a new era: the Agricultural Revolution and the Industrial Revolution (which depended on fossil fuels). It is worth noting that these unusual transitions have not resulted from unbridled human creativity. Rather, they emerged from solutions to problems of resource shortages, and were adopted reluctantly because initially they created diminishing returns on effort in peoples' daily lives (Cohen, 1977; Wilkinson, 1973).

Most of the time, cultural complexity increases in a purely mundane manner: from day-to-day exercises in solving problems. Most importantly for this essay, complexity that emerges in this way will usually appear *before* there is additional energy to support it. Complexity thus compels increases in resource production. Rather than following the availability of energy, cultural complexity often precedes it. Energy lags complexity rather than the reverse. This new understanding of the temporal relationship between complexity and resources has implications for sustainability that diverge from what is commonly assumed. These implications will be explored at the end of this essay. It is useful first to present historical case studies that illustrate the points made in this section.

III. CASE STUDIES IN ENERGY AND COMPLEXITY

I describe next two historical cases that illustrate the relationship of resources to problem solving and complexity. These are the collapse of the Western Roman Empire in the fifth century A.D. and the collapse of the Byzantine Empire in the seventh century A.D., followed by Byzantine recovery. These cases are chosen for the lessons they impart about sustainability today.

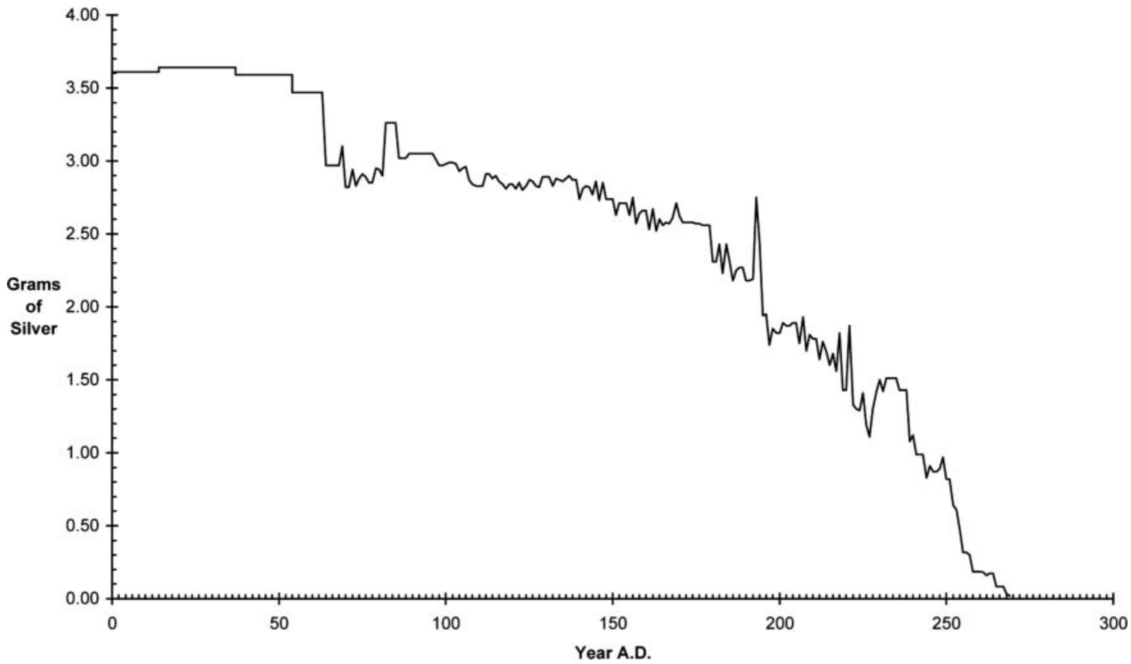

FIG. 2. Debasement of the denarius to 269 A.D. Source: Tainter (1994).

A. Collapse of the Western Roman Empire

The economics of an empire such as the Romans assembled are seductive but illusory. The returns to any campaign of conquest are highest initially, when the accumulated surpluses of the conquered peoples are appropriated. Thereafter the conqueror assumes the cost of administering and defending the province. These responsibilities may last centuries, and are paid for from yearly agricultural surpluses.

The Roman government was financed by agricultural taxes that barely sufficed for ordinary administration. When extraordinary expenses arose, typically during wars, the precious metals on hand frequently were insufficient. Facing the costs of war with Parthia and rebuilding Rome after the Great Fire, Nero began in 64 A.D. a policy that later emperors found irresistible. He debased the primary silver coin, the denarius, reducing the alloy from 98 to 93 percent silver. It was the first step down a slope that resulted two centuries later in a currency that was worthless and a government that was insolvent (Figure 2).

In the half-century from 235 to 284 the empire nearly came to an end. There were foreign and civil wars almost without interruption. The period witnessed 26 legitimate emperors and perhaps 50 usurpers. Cities were sacked and frontier provinces devastated. The empire shrank in the 260s to Italy, the Balkans, and North Africa. By prodigious effort the empire survived the crisis, but it emerged at the turn of the fourth century A.D. as a very different organization.

In response to the crises, Diocletian and Constantine, in the late third and early fourth centuries, designed a government that was larger, more complex, and more highly organized. They doubled the size of the army. To pay for this the government taxed its citizens more heavily, conscripted their labor, and dictated their occupations. Villages were responsible for the taxes on their members, and one village could even be held liable for another. Despite several monetary reforms a stable currency could not be found (Figure 3).

As masses of worthless coins were produced, prices rose higher and higher. Money-changers in the east would not convert imperial currency, and the government refused to accept its own coins for taxes.

With the rise in taxes, population could not recover from plagues in the second and third centuries. There were chronic shortages of labor. Marginal lands went out of cultivation. Faced with taxes, peasants would abandon their lands and flee to the protection of a wealthy landowner. By 400 A.D. most of the lands of Gaul and Italy were owned by about 20 senatorial families.

From the late fourth century the peoples of central Europe could no longer be kept out. They forced their way into Roman lands in western Europe and North Africa. The government came to rely almost exclusively on troops from Germanic tribes. When finally they could not be paid, they overthrew the last emperor in Italy in 476 (Boak, 1955; Russell, 1958; Jones, 1964, 1974; Hodgett, 1972; MacMullen, 1976; Wickham, 1984; Williams, 1985; Tainter, 1988; 1994; Duncan-Jones, 1990; Harl, 1996).

The strategy of the later Roman Empire was to respond to a near-fatal challenge in the third century by increasing the size, complexity, power, and costliness of the primary problem-solving system—the government and its army. The higher costs were undertaken not to expand the empire or to acquire new

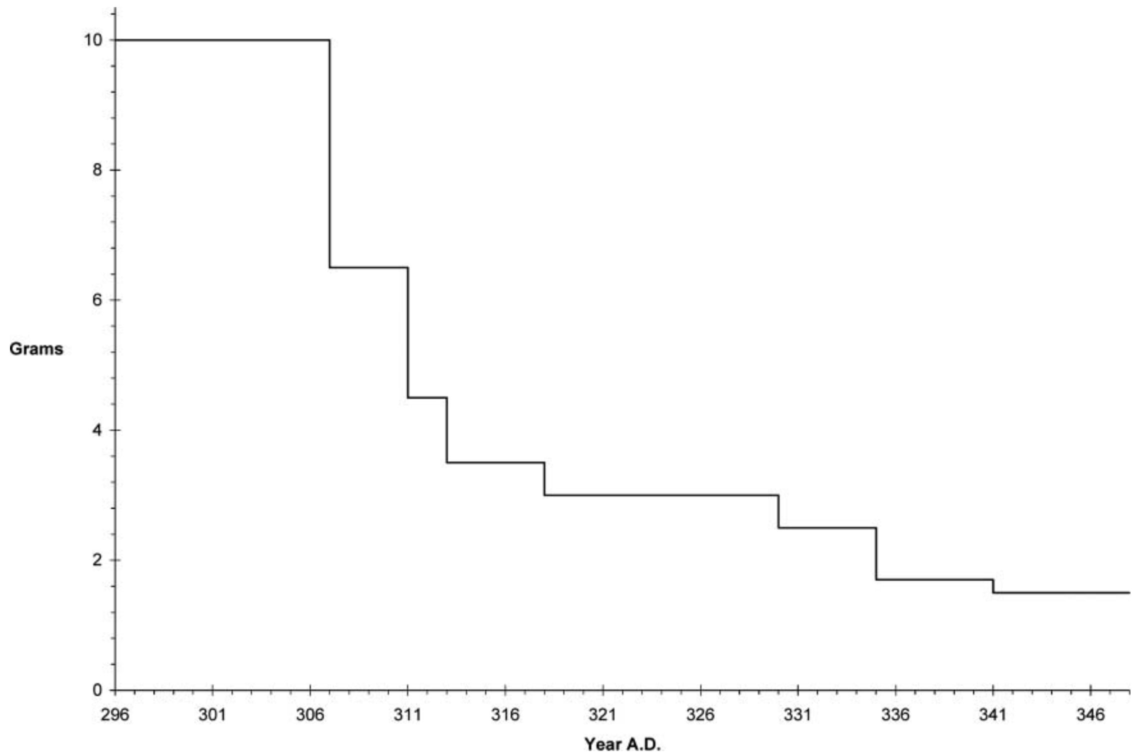

FIG. 3. Reductions in the weight of the follis, 296 to 348 A.D. (data from Van Meter, 1991).

wealth, but to maintain the status quo. The benefit/cost ratio of imperial government declined. In the end the Western Roman Empire could no longer afford the problem of its own existence (Tainter, 1988, 1994, 2000, 2006; Allen, Tainter, and Hoekstra, 2003; Tainter and Crumley, 2007).

B. Collapse and Recovery of the Byzantine Empire

The Eastern Roman Empire (usually known as the Byzantine Empire) survived the fifth century debâcle. Efforts to develop the economic base, and to improve the effectiveness of the army, were so successful that by the mid sixth century Justinian (527–565) could engage in a massive building program and attempt to recover the western provinces.

By 541 the Byzantines had conquered North Africa and most of Italy. Then that year bubonic plague swept over the Mediterranean for the first time. Just as in the fourteenth century, the plague of the sixth century killed from one-fourth to one-third of the population. The loss of taxpayers caused immediate financial and military problems. In the early seventh century the Slavs and Avars overran the Balkans. The Persians conquered Syria, Palestine, and Egypt. Constantinople was besieged for seven years.

The emperor Heraclius cut pay by half in 616, and proceeded to debase the currency (Figure 4).

These economic measures facilitated his military strategy. In 626 the siege of Constantinople was broken. The Byzantines destroyed the Persian army and occupied the Persian king's favorite residence. The Persians had no choice but to surrender all the territory they had seized. The Persian war lasted 26 years, and resulted only in restoration of the status quo of a generation earlier.

The empire was exhausted by the struggle. Arab forces, newly converted to Islam, defeated the Byzantine army decisively in 636. Syria, Palestine, and Egypt, the wealthiest provinces, were lost permanently. The Arabs raided Asia Minor nearly every year for two centuries, forcing thousands to hide in underground cities. Constantinople was besieged each year from 674 to 678. The Bulgars broke into the empire from the north. The Arabs took Carthage in 697. From 717 to 718 an Arab force besieged Constantinople continuously for over a year. It seemed that the empire could not survive. The city was saved in the summer of 718, when the Byzantines ambushed reinforcements sent through Asia Minor, but the empire was now merely a shadow of its former size.

Third- and fourth-century emperors had managed a similar crisis by increasing the complexity of administration, the regimentation of the population, and the size of the army. This was paid for by such levels of taxation that lands were abandoned and peasants could not replenish the population. Byzantine emperors could hardly impose more of the same exploitation on the depleted population of the shrunken empire. Instead they adopted a strategy that is truly rare in the history of complex societies: systematic simplification.

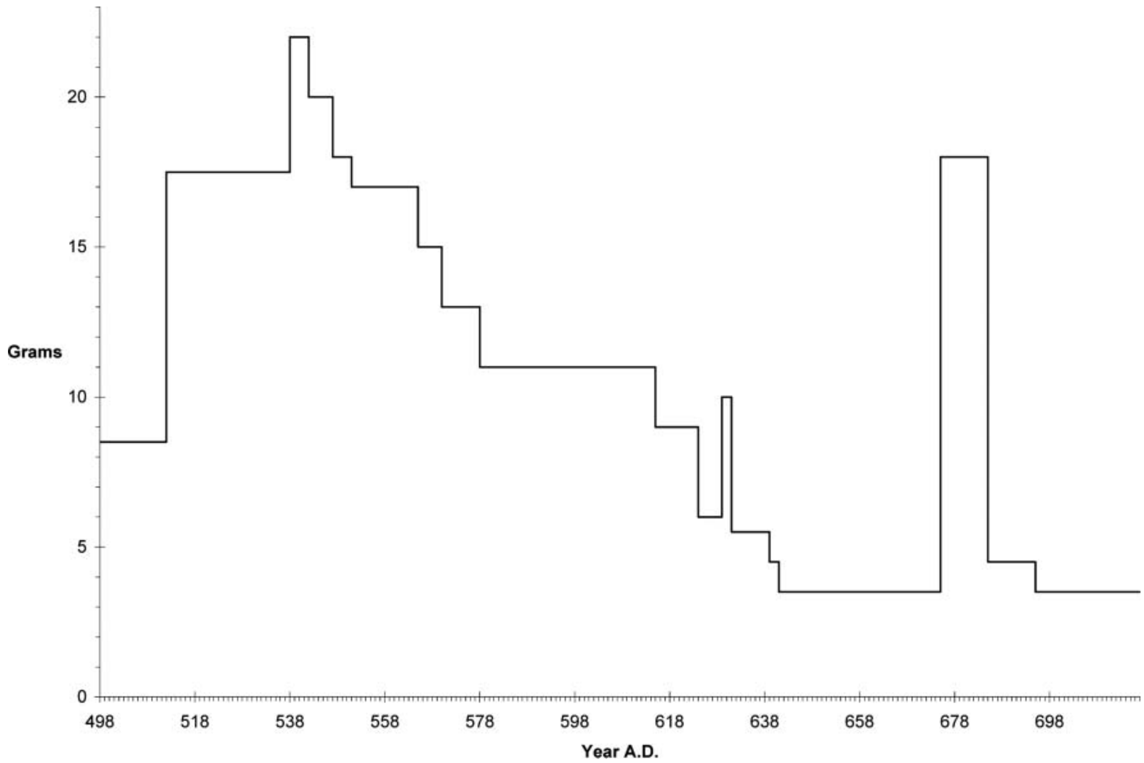

FIG. 4. Weight of the Byzantine follis, 498–717 A.D. (data from Harl, 1996).

Around 659 military pay was cut in half again. The government had lost so much revenue that even at one-fourth the previous rate it could not pay its troops. The solution was for the army to support itself. Soldiers were given grants of land on condition of hereditary military service. The Byzantine fiscal administration was correspondingly simplified.

The transformation ramified throughout Byzantine society. Both central and provincial government were simplified, and the costs of government were reduced. Provincial civil administration was merged into the military. Cities across Anatolia contracted to fortified hilltops. The economy developed into its medieval form, organized around self-sufficient manors. There was little education beyond basic literacy and numeracy, and literature itself consisted of little more than lives of saints. The period is sometimes called the Byzantine Dark Age.

The simplification rejuvenated Byzantium. The peasant-soldiers became producers rather than consumers of the empire's wealth. By lowering the cost of military defense the Byzantines secured a better return on their most important investment. Fighting as they were for their own lands and families, soldiers performed better.

During the next century, campaigns against the Bulgars and Slavs gradually extended the empire in the Balkans. Greece was recaptured. Pay was increased after 840, yet gold became so plentiful that in 867 Michael III met an army payroll by melting down 20,000 pounds of ornaments from the throne room. When marines were added to the imperial fleet it became more effective against Arab pirates. In the tenth century the Byzantines reconquered parts of coastal Syria. Overall after 840 the size of the empire was nearly doubled. The process culminated when Basil II (963–1025) conquered the Bulgars and extended the empire's boundaries again to the Danube (Treadgold, 1988, 1995, 1997; Haldon, 1990; Harl, 1996). In two centuries the Byzantines had gone from near disintegration to being the premier power in Europe and the Near East, an accomplishment won by decreasing the complexity and costliness of problem solving.

IV. DISCUSSION

The Roman and Byzantine case studies illustrate different outcomes to complexification, and offer different lessons for understanding sustainability. The Roman collapse exemplifies the thesis of this essay, that increasing complexity precedes the availability of energy and subsequently compels increases in its production. The Byzantine collapse and recovery illustrate a different but also important point, which will be discussed later.

The Roman Empire is a single case study in complexity and problem solving (for others, see Tainter, 1988, 2000, 2002, 2006; Allen *et al.*, 2003), but it is an important and representative one. It illustrates one of the basic processes by which societies increase in complexity. Societies adopt increasing complexity to solve problems, becoming at the same time more costly. In the normal course of economic evolution, this process at some point will produce diminishing returns. Once diminishing returns set in, a problem-solving institution must either find new resources to continue the activity, or fund the activity by reducing the share of resources available to other economic sectors. The latter is likely to produce economic contraction, popular discontent, and eventual collapse. This was the fate of the Western Roman Empire.

This understanding of complexity and resources has implications for our contemporary discussions of energy and sustainability. Both popular and academic discourse on sustainability commonly make the following assumptions: that (a) future sustainability requires that industrial societies consume a lower quantity of resources than is now the case (e.g., Brown, 2008; Caldararo, 2004; Heinberg, 2004), and (b) sustainability will result automatically if we do so. Sustainability emerges, in this view, as a passive consequence of consuming less. Thus sustainability efforts are commonly focused on reducing consumption through voluntary or enforced conservation, perhaps involving simplification, and/or through improvements in technical efficiencies.

The common perspective on sustainability follows logically from the progressivist view that resources precede and facilitate innovations that increase complexity. Complexity, in this view, is a voluntary matter. Human societies became more complex by choice rather than necessity. By this reasoning, we should be able to choose to forego complexity and the resource consumption that it entails. Progressivism leads to the notion that societies can deliberately reduce their consumption of resources and thus achieve sustainability. Regrettably, we know that progressivism is a flawed argument, failing to provide an accurate account of history.

The fact that complexity and costliness increase through mundane problem solving suggests a different conclusion with a startling implication: Contrary to what is typically advocated as the route to sustainability, *it is usually not possible for a society to reduce its consumption of resources voluntarily over the long term*. To the contrary, as problems great and small inevitably arise, addressing these problems requires complexity and resource consumption to increase. Historically, as illustrated by the Roman Empire and other cases (Tainter, 1988, 2000, 2002, 2006; Allen *et al.*, 2003), this has commonly been the case.

The Byzantine collapse becomes important at this point. It is the only case of which I am aware in which a large, complex society systematically simplified, and reduced thereby its consumption of resources. While this case shows that societies can reduce resource consumption and thrive, it offers no hope that this can be done commonly. In the Byzantine case simplification was forced, made necessary by a gross insufficiency of revenues. The Byzantines undertook simplification and conservation because, to use a colloquial expression, their backs were to the wall. The empire had no choice. The Byzantine simplification was also temporary. As Byzantine finances recovered, emperors again expanded the size and complexity of their armed forces (McGeer, 1995; Treadgold, 1995). The Byzantine chronicler Anna Comnena, daughter of emperior Alexius I (1081–1118), described her father's marching army as like a moving city (Haldon, 1999).

Many students of sustainability will find it a disturbing conclusion that long-term conservation is not possible, contravening as it does so many assumptions about future sustainability. Naturally we must ask: are there alternatives to this process? Can we find a way out of this dilemma? Regrettably, as Boulding observed, no simple solutions are evident. Consider some of the approaches commonly advocated:

1. *Voluntarily Reduce Resource Consumption*. While this may work for a time, its longevity as a strategy is constrained by the factors discussed in this essay: Societies increase in complexity to solve problems, becoming more costly in the process. Resource production must subsequently increase to fund the increased complexity. To implement voluntary conservation long term would require that a society be either uniquely lucky in not being challenged by problems, or that it not address the problems that confront it. The latter strategy would at best reduce the legitimacy of the problem-solving institution, and at worst lead to its demise.

I will not address in depth the question whether long-term voluntary conservation is possible at the level of individuals and households. I am confident that usually it is not, that humans will not ordinarily forego affordable consumption of things they desire on the basis of abstract projections about the future. I raise the possibility of voluntary conservation only because of its perennial popularity.

There are societies that seem to incorporate an ethic of conservation. Japan, as described by Caldararo (2004), may be such a society. Caldararo argues that Japan participates in the system of industrial nations in its own way: low fertility, comparatively low consumption, high savings, acceptance of high prices, and tolerance of institutions that are economically inefficient but socially rational. "Japan," Caldararo believes, "is building a sustainable economy for the 21st century" (2004). Yet even if Caldararo's assessment is accurate, such a case does not contravene the arguments presented here. Even in societies that do voluntarily consume less than they could, problem solving must in time cause complexity, costliness, and resource consumption to grow. These things may grow from a smaller base, but the fundamental process of increasing complexity remains unaltered.

2. *Employ the Price Mechanism to Control Resource Consumption*. This is currently the *laissez-faire* strategy of industrialized nations. Since humans don't commonly forego affordable consumption of desired goods and services, economists consider it more effective than voluntary conservation. Both approaches, however, lead eventually to the same outcome: As problems arise, resource consumption must increase at the societal level even if consumers as individuals purchase less.

3. *Ration Resources*. Because of its unpopularity, rationing is possible in democracies only for clear, short-term emergencies. This is illustrated by the reactions to rationing in England and the

United States during World War II. Moreover, rationed resources may become needed to solve societal problems, belying any attempt to conserve through rationing. Something like this can be seen in the fiscal stimulus programs enacted in late 2008 and early 2009.

4. *Reduce Population*. While this would reduce aggregate resource consumption temporarily, as a long-term strategy it has the same fatal flaw as the first two: Problems will emerge that require solutions, and those solutions will compel resource production to grow.

5. *Hope for Technological Solutions*. I sometimes call this a faith-based approach to our future. We members of industrialized societies are socialized to believe that we can always find a technological solution to resource problems. Technology, within the framework of this belief, will presumably allow us continually to reduce our resource consumption per unit of material well-being. Conventional economics teaches that to bring this about we need only the price mechanism and unfettered markets. Consider, for example, the following statements:

- No society can escape the general limits of its resources, but no innovative society need accept Malthusian diminishing returns (Barnett and Morse, 1963),
- All observers of energy seem to agree that various energy alternatives are virtually inexhaustible (Gordon, 1981),
- By allocation of resources to R&D, we may deny the Malthusian hypothesis and prevent the conclusion of the doomsday models (Sato and Suzawa, 1983).

Our society's belief in technical solutions is deeply ingrained.

The flaw here was pointed out by Jevons (1866), as noted above: as technological improvements reduce the cost of using a resource, total consumption will eventually increase. The Jevons Paradox (also known as the Rebound Effect) is widely in effect (Polimeni *et al.*, 2008), among economic levels ranging from nations to households and individuals, including in many sectors of daily life (Tainter, 2008).

Thus, conventional solutions to problems of resource consumption can only be effective for short periods of time. Over the long term, problem solving compels societies to grow in complexity and increase consumption. Because of this it is useful to think of sustainability in the metaphor of an athletic game: it is possible to "lose"—that is, to become unsustainable, as happened to the Western Roman Empire. But the converse does not hold. Because we continually confront challenges, there is no point at which a society has "won"—become sustainable in perpetuity, or at least for a very long time. Success, rather, consists of remaining in the game.

What can societies do when faced with increasing complexity, increasing costs, and diminishing returns in problem solving? There appear to be seven possible strategies, *all of which are effective only for a time* (Tainter, 2006). These are not sequential steps, nor are they mutually exclusive. They are simply ideas that can work alone or in combination. Some of these strategies would clearly have only short-term effects, while others may be effective for longer. The first strategy, however, is essential in all long-term efforts toward sustainability.

1. *Be aware*. Complexity is most insidious when the participants in an institution are unaware of what causes it. Managers of problem-solving institutions gain an advantage by understanding how complexity develops, and its long-term consequences. It is important to understand that unsustainable complexity may emerge over periods of time stretching from years to millennia, and that cumulative costs bring the greatest problems.

2. *Don't solve the problem*. This option is deceptively simple. As obvious as it seems, not solving problems is a strategy that is rarely adopted. The world view of Western industrial societies is that ingenuity and incentives can solve all problems. Ignorance of complexity, combined with the fact that the cost of solving problems is often deferred or spread thinly, reinforces our problem-solving inclination. Yet often we do choose not to solve problems, either because of their cost or because of competing priorities. Appropriators and managers do this routinely.

3. *Accept and pay the cost of complexity*. This is a common strategy, perhaps the most common in coping with complexity. It too is deceptively simple. Governments are often tempted to pay the cost of problem solving by increasing taxes, which reduces the share of national income available to other economic sectors. Businesses may do the same by increasing prices. The problem comes when taxpayers and consumers rebel, or when a firm's competitors offer a similar product at a lower cost.

4. *Find subsidies to pay costs*. This has been the strategy of modern industrial economies, which have employed the subsidies of fossil and nuclear energy to support our unprecedented levels of complexity. As seen since the adoption of coal (Wilkinson, 1973), the right subsidies can sustain complex problem solving for centuries. Anxiety over future energy is not just about maintaining a standard of living. It also concerns our future problem-solving abilities.

5. *Shift or defer costs*. This is one of the most common ways to pay for complexity. Budget deficits, currency devaluation, and externalizing costs exemplify this principle in practice. This was the strategy of the Roman Empire in debasing its currency, which shifted to the future the costs of containing current crises. Governments before the Roman Empire also practiced this subterfuge, as have many since. As seen in the case of the Romans, it is a strategy that can work only for a time. When it is no longer feasible, the economic repercussions may be far worse than if costs had never been deferred.

6. *Connect costs and benefits*. If one adopts the explicit goal of controlling complexity, costs and benefits must be connected so explicitly that the tendency for complexity to grow can be constrained by its costs. In an institution this means that information about the cost of complexity must flow accurately and effectively. Yet in a hierarchical institution, the flow of information from the bottom to the top is frequently inaccurate and ineffective (McIntosh *et al.*, 2000). Thus the managers of an

institution are often poorly informed about the cost of complexity and feel free to deploy more.

7. *Recalibrate or revolutionize the activity*. This involves a fundamental change in how costs and benefits are connected, and is potentially the most far-reaching technique for coping with complexity. The strategy may involve both new resources and new types of complexity that lower costs, combined with positive feedback among new elements that amplifies benefits and produces growth. As noted above, true revolutions of this sort are rare, so much so that we recognize them in retrospect with a term signifying a new era: the Agricultural Revolution and the Industrial Revolution. Today's Information Revolution may be another such case. Fundamental changes of this sort depend on opportunities for positive feedback, where elements reinforce each other. For example, Watt's steam engine facilitated the mining of coal by improving pumping water from mines. Cheaper coal meant more steam engines could be built and put to use, facilitating even cheaper coal (Wilkinson, 1973). Put a steam engine on rails and both coal and other products can be distributed better to consumers. Combine coal, steam engines, and railroads, and we had most of the components of the Industrial Revolution, all mutually reinforcing each other. The economic system became more complex, but the complexity involved new elements, connections, and subsidies that produced increasing returns.

The transformation of the U.S. military since the 1970s provides a more recent example. So profound is this transformation that it is recognized by its own acronym: RMA, the revolution in military affairs. The revolution involves extensive reliance on information technology, as well as the integration of hardware, software, and personnel. Weapons platforms are just part of this revolution, since weapons now depend on integration with sensors, satellites, software, and command systems (Paarlberg, 2004). This is a military that is vastly more complex than ever before. That complexity is of course costly, but the benefits include both greater effectiveness and significant cost savings. Being able to pinpoint targets means less waste of ordinance, less need for large numbers of weapons platforms, and a need for fewer people.

The fact that such revolutions do occur gives hope that a way out of our current dilemma may be found. Yet complex systems at the societal level cannot be designed. They emerge on their own or they don't. To rely on some hoped-for revolution involving innovation, energy, and positive feedback is, like relying on technological innovation, a faith-based approach to our future.

V. CONCLUDING REMARKS

Sustainability is not the achievement of stasis. It is not a passive consequence of having fewer humans who consume more limited resources. One must work at being sustainable. The challenges to sustainability that any society (or other institution) might confront are, for practical purposes, endless in number and infinite in variety. This being so, sustainability is a matter of problem solving, an activity so commonplace that we perform it with little thought to its long-term implications.

The notion of progress is ingrained in industrial societies, so much so that it is part of our cosmology, a fundamental element of our ancestor myth. Just as our ancestors, we believe, "pulled themselves up" through ingenuity, so today we continue this tradition. In the conventional framework, all that past societies required for innovation and progress was free time emerging from a sufficient level of energy and other resources. Complexity, it is believed, follows energy, and if this is so then we should be able to forego complexity voluntarily and reduce our consumption of the resources that it requires. This is the conventional approach to sustainability, which implicitly sees the future as a condition of stasis with no challenges.

In actuality, major infusions of surplus energy are rare in human history. More commonly, complexity increases in response to problems, problems that are sometimes large-scale and urgent. Increased complexity requires increased resources, although when a problem is addressed long-term costs are typically not considered fully. Complexity emerging through problem solving typically precedes the availability of energy, and compels increases in its production. Energy follows complexity. Complexity is not voluntary, nor is it something that we can ordinarily choose to forego. Complexity is required to solve problems.

Applying this understanding to the problem of sustainability leads to two conclusions that are not presently recognized in the sustainability movement. The first is that the solutions commonly recommended to promote sustainability—conservation, simplification, pricing, and innovation—can do so only in the short term. Secondly, long-term sustainability depends on solving major societal problems that will converge in coming decades, and this will require increasing complexity and energy production. Sustainability is demonstrably not a condition of stasis. It is, rather, a process of continuous adaptation, of perpetually addressing new or ongoing problems and securing the resources to do so. Developing new energy is therefore the most fundamental thing we can do to become sustainable.

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