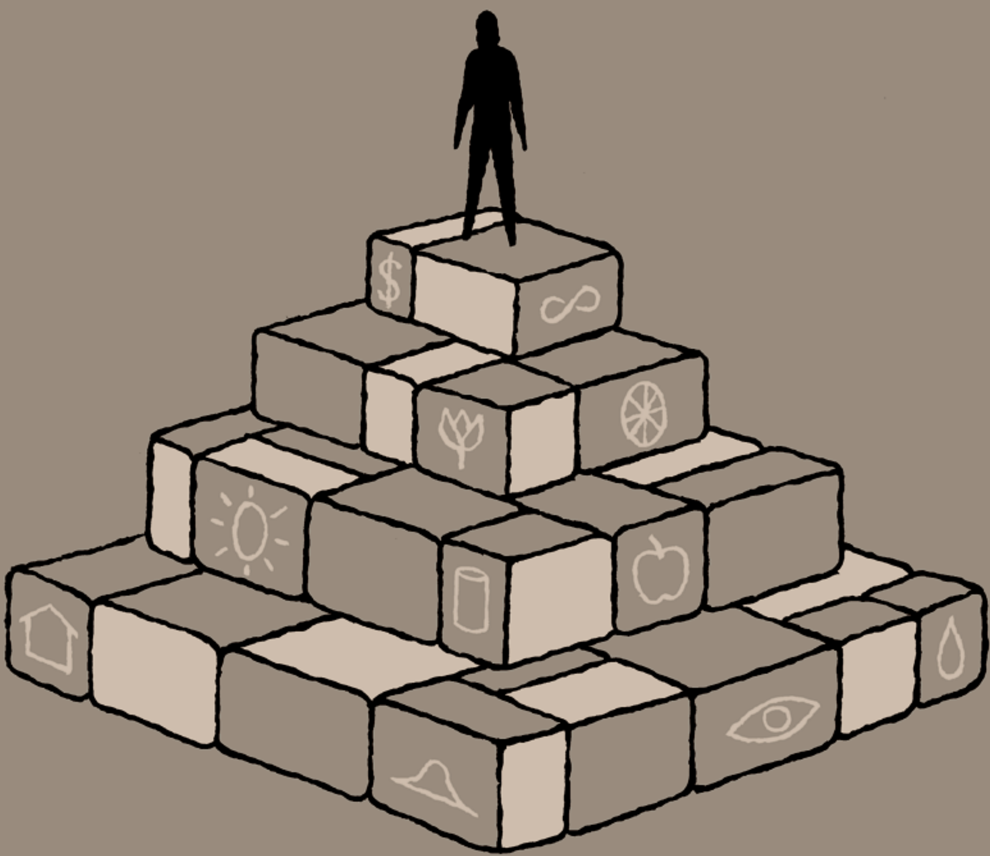
The Post Carbon Reader Series: Foundation Concepts

Thinking "Resilience"

By William E. Rees, FRSC



About the Author

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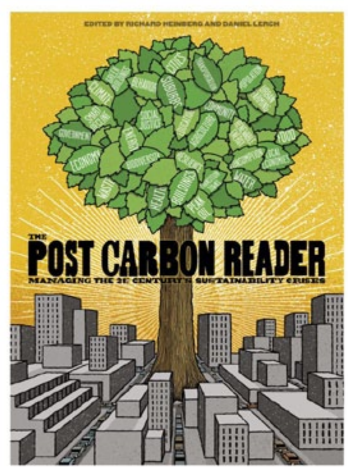

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Industrial society remains utterly dependent on ecosystems to continue providing life support.

The Emergence of "Resilience" Thinking

During the past two centuries, life was clearly getting easier and better for many people. The Enlightenment had seemingly abolished superstition as a major influence in the affairs of the Western world while its offspring, modern science, gave humans apparent mastery of matter and the ability to shape the material world to their own purposes. Through much of the twentieth century, progress, or at least what some now call "the progress myth," seemed primed to become a permanent reality. Medicine eliminated many of the scourges that had historically kept humanity's population in check even as industrial agriculture—Malthus notwithstanding—ensured that food production exploded even faster than population. Longevity doubled in many developing countries,[1] while rising incomes, shorter workweeks, unprecedented personal mobility (the private automobile), and the accelerating proliferation of laptops, cell phones, iPods, and other electronic gadgetry ensured that increasingly wealthy millions didn't lack options to fill their longer lives, either at work or at play.

Then the warning signs began to accumulate. Various science-based resource-management strategies that initially seemed successful subsequently crashed and burned:

- Agricultural pesticides once promised to eradicate crop-damaging insects, but dozens of crop-damaging insect species have since evolved immunity and crop losses are as great as ever.
- Fire control, once a mainstay of sound forest management, is now known to turn many protected forests into explosive tinderboxes prone to unstoppable wildfire (as any devotee of a burned-out Yellowstone National Park can readily testify).
- Despite the promise that modern fisheries science and economics could deliver "maximum sustained yield," we have witnessed the repeated collapse of fisheries around the world, to the despair of both fisheries managers and dependent human communities.

Just as worrisome, various management efforts to reverse these negative trends or repair ecosystem damage have failed. For example:

- The North Atlantic cod stocks that collapsed in 1992 have not recovered despite an eighteen-year-and-counting moratorium on fishing. (The cod are not extinct, but their ecosystems have changed in ways that prevent them from reoccupying their former niche.)
- Massive clear-cuts in the Pacific Northwest have not responded to reforestation efforts as expected.
- The south polar ozone hole shows little sign of recovery, despite the 1987 Montreal Protocol to phase out ozone-destroying gases (regarded as the most

successful example of international cooperation to solve a global environmental problem).

As if to underscore the increasing scale of the problem, the oil spills, pesticide scares, and other mainly local pollution incidents that grabbed headlines in the 1960s and 1970s have evolved into the ozone depletion, acid rain, climate change, and other global-scale concerns that have dominated the environmental headlines from the 1980s to the present day.

Ecologists have come to believe that the unexpected systems failures illustrated by these examples are not mere aberrations but are actually the *norm* for ecosystems under steadily increasing exploitation pressure. This implies, for example, that conventional harvesting models based on earlier resource-management concepts are seriously flawed—they do not adequately reflect the functional dynamics of systems under stress. And many critical ecosystems on every continent and in all the world's oceans *are* under stress. The sheer scale of human demands on nature has pushed many socio-ecosystems into unfamiliar and often unfriendly territory.[2] The transition is often unexpected, rapid, and tragic for dependent human populations.

Just what is going on here? One explanation is that overstressed socio-ecosystems gradually lose their "resilience," which is defined as *the capacity of a system to withstand disturbance while still retaining its fundamental structure, function, and internal feedbacks*.[3] Experience shows that, over time, simplified intensively managed systems become more inflexibly "brittle" and thus more prone to erratic behavior (including systems collapse) than they were at earlier stages of "development." To put it another way, excessive human activity—either resource exploitation or waste production—can erode the functional integrity of the same ecosystems that make these human activities possible. Ironically, there are also cases in which human purposes are *frustrated* by natural resilience, such as when insect species evolve immunity to pesticides. The adaptive responses of highly resilient ecosystems or components can thus defeat our best management efforts.

Since techno-industrial society remains utterly dependent on ecosystems to continue providing life support, learning how best to cultivate systems resilience must become a key element of sustainability thinking.

Getting at the Root of the Problem

> We have in our hands now… the technology to feed, clothe, and supply energy to an ever-growing population for the next 7 billion years.
> —*Julian Simon*[4]

> Can you think of any problem in any area of human endeavor on any scale, from microscopic to global, whose long-term solution is in any demonstrable way aided, assisted, or advanced by further increases in population, locally, nationally, or globally?
> —*Albert A. Bartlett*[5]

How is it that our allegedly science-based culture could produce such a conundrum? Part of the problem is that modern industrial society operates from a "normal-science" perspective that takes a narrowly mechanistic approach to the biophysical world. For example, most economic thinking and related resource-management policy assume direct, short-term, reversible cause-effect relationships between human activities and ecosystem responses, and also that the world generally gravitates toward a single equilibrium. Resource management may acknowledge that ecosystems, social systems, and socio-ecosystems are complicated, but it also assumes that, given sufficient data, their "nature" is knowable and predictable. In any case, our models typically assume that any changes in exploited systems will be incremental, obvious, direct, and manageable.

From this perspective, the role of science is to control the natural world for human purposes—there are no limits on growth or constraints on human ingenuity. Standard resource-management models are therefore almost entirely anthropocentric and utilitarian. Traditional management strategies strive to enhance the efficiency of growth by *minimizing* the annoying variability in natural ecosystems and *maximizing* the production of systems components and variables of value to people (e.g., food crops, fish catches, GDP per capita).[6] And, of course, once the system has been engineered into some optimally efficient configuration, the focus is on trying to keep it there (invariably at the expense of other variables and system components). The implicit assumption in all this is that "uncertainty in nature [can be] replaced by the certainty of human control."[7] Little thought is given to the effect of exploitation on non-target systems components or on events and processes at higher and lower scales in the total ecosystem complex (see box 3.1).

Traditional production-oriented approaches to resource management can succeed temporarily—indeed, the North Atlantic cod stocks were fished for several centuries before they collapsed in the early 1990s. However, the record of modern management failures makes clear that the mechanistic thinking upon which management efforts are based does not capture the full structural complexity and behavioral dynamics of real-world socioecological systems. Natural ecosystems do not operate continuously in some optimal state; nature does not set out to maximize specific variables or particular species. Ecosystems are constantly in flux and are normally able to function over a wide range of natural variability. Indeed, the adaptability and tolerance of constituent species have been set by the extremes to which those species and species complexes have been exposed in the course of evolutionary history, not by arbitrary "optimal" conditions.

It therefore should not be surprising that attempting to force the system down some narrow productivity channel in the service of human needs affects how that system functions and behaves. One effect is to make the system more vulnerable to what would otherwise be normal shocks and disturbances. Ecosystems are self-organizing, self-producing systems in which each major component exists in vital relationship with other components. These relationships must be maintained if the components are to continue being able to produce themselves and the system is to retain its functional

BOX 3.1
Trade and Globalization

Perhaps the most sweeping example of the "growth-through-efficiency" mode of thinking is the modern preoccupation with "free trade" and globalization. Breaking down the barriers among national economies makes it possible for each country to specialize in those few products or services for which it has a domestic "comparative advantage"—that is, products that it can produce with the fewest inputs—and to trade for all the rest. Since each nation will theoretically be operating at maximum efficiency, global output per unit input will be maximized and everyone should be materially better off.

Importantly, this singular emphasis on maximizing growth through trade assumes a stable world and unchanging market conditions—that is, that there are few risks associated with either specialization or trade dependence. Governments thus willingly sacrifice other values such as national diversity and self-reliance on the altar of efficiency.

But what happens if technology or markets change so that demand for Country A's products disappears? What is Country B to do if its customary sources for food imports are jeopardized by climate change and it no longer has a functional domestic agricultural sector to fill the gap? The fact is that the real world is one of rapid ecological and cultural change, and in these circumstances perhaps nations should be asking whether narrow specialization and trade or greater structural diversity for self-reliance would better serve their needs for enhanced socioeconomic resilience.

integrity.[8] When humans maximize the harvest of a particular species, for example, we inadvertently alter that species' relationships to multiple other species (e.g., predators and prey) in the ecosystem, setting off a cascade of feedback responses that can fundamentally erode the system's integrity. Some species may be lost, others may be favored, and, ultimately, the system may cease to function in ways that are necessary to sustain either the target species or their human predators.

In short, the evidence suggests that in addition to overharvesting, efficiency-oriented maximum production strategies simplify both exploited ecosystems and the social systems they support. They eliminate important processes and redundancies, and make the socio-ecosystem more vulnerable to additional stress. The system loses resilience.

The Antidote: Complex Systems Science

> There is no sustainable "optimal" state of an ecosystem, a social system or the world. It is an illusion, a product of the way we look at and model the world. It is unattainable... and yet it is a widely pursued goal.
> —*David Walker and Brian Salt*[9]

Science evolves through experiments, both intentional and unplanned. Resource management based on "normal" linear, reductionist thinking was, in effect, a grand unplanned experiment that has served to test existing theory and assumptions about systems behavior. The ultimate failure of the maximum production model can therefore be interpreted as a signal event that forced a revolution in scientists' thinking about natural systems.

Recent decades have seen the emergence of what is sometimes called "post-normal" science, based on a more refined and humble view of complex systems behavior. The goal is twofold: First, to develop a more comprehensive and integrative theory to explain responses to change in interlinked ecological, social, and economic systems across scales in both time and space; second, to better assist people to adapt resiliently to supportive ecosystems that are themselves constantly adapting (including adapting to human intervention!).

The emerging integrative theory accepts—even embraces—uncertainty and unpredictability.[10] Because living systems exist in changing physical environments, they too are constantly changing and adapting. In these circumstances, reliable prediction is limited to narrow domains of relative stability, and the size and boundaries of those domains may themselves be shifting.[11] Surprise and structural change are inevitable in complex systems, particularly socio-ecosystems in which humans are exploiting nature.

Science has also come to recognize that complex systems behavior is nonlinear—there may be significant temporal lags between cause and effect such that damage is not apparent until long after the causal event.[12] Even more problematic, socio-ecosystems are characterized by moving thresholds or "tipping points" whose existence may be unknown until they have been breached (this is just one form of uncertainty that may be inherently irreducible). The problem is that once some key system component—or even a whole subsystem—has crossed a threshold, it may gravitate into a new quasi-stable regime from which it may not easily be extracted. One of the hardest lessons of our great unplanned experiment is that complex systems generally have multiple possible equilibrium states, some of which may be hostile to human needs and purposes.[13]

In these circumstances, mechanical assumptions must give way to dynamic analysis. The role of science shifts from facilitating the restructuring of nature to helping people adapt to natural variability. On the front lines, resource managers must replace assumptions of certain control with cautious humility as the goal of resource extraction shifts from maximization to sufficiency (and even avoiding catastrophe!). Clearly, planning for sustainability requires that we develop new ways to

Understanding and coping with change is at the heart of resilience thinking.

collect, evaluate, and integrate available information. What do we need to know to enable society to adapt to inevitable change? What kinds of information help to foster novelty and innovation in response to inevitable change? Can we learn to distinguish between useful and dangerous information so that we avoid counterproductive policy decisions?

What Is Resilience Thinking?

"Resilience thinking" is one response to the foregoing questions. "The bottom line for sustainability is that any proposal for sustainable development that does not explicitly acknowledge a system's resilience is simply not going to keep delivering the goods (or services)."[14] Resilience science is based on the simple premise that change is inevitable and that attempts to resist change or control it in any strict sense are doomed to failure. Resilience science is also systems science.

Based on the previous analysis, resilience thinking:

- Accepts that the human enterprise is structurally and functionally inseparable from nature. That is, the human enterprise is a fully embedded, totally dependent subsystem of the ecosphere—people live *within* socio-ecosystems. Human activities can therefore significantly affect the integrity and behavior of supportive ecosystems and these changes immediately feed back to affect the state of the human subsystem. We can no longer understand the dynamics of either the natural system or the human subsystem in isolation without understanding the dynamics of the other component.
- Understands that linked/integrated socio-ecosystems are constantly changing in response to both internal and external forces—they are dynamic complex adaptive systems. The changes within these systems are not linear, smooth, or predictable, particularly outside the systems' "normal" regime. Indeed, under sufficient pressure, critical systems variables may "flip" (cross a threshold) into a different regime or alternative stable state. In other words, like natural ecosystems, socio-ecosystems also have multiple possible equilibria, some of which may not be amenable to continued human use or existence (remember the collapse of the North Atlantic cod fishery).
- Recognizes that the sustainability of the human enterprise on a crowded and resource-stressed planet depends on our ability to conserve the resilience of socioecological systems. In this context, resilience defines the capacity of the system to assimilate disturbances without crossing a threshold into an alternative and possibly less "friendly" stable state. A desirable socioecological system characterized by high resilience is able to resist external disturbance and continue to provide biophysical goods and services essential for a satisfactory quality of life.[15]

- Further recognizes that, for sustainability, resource-management efforts must shift from reshaping nature for the purpose of satisfying human demands to moderating human demands so that they fit within biophysical limits. They must do this in a way that is consistent with both the productive and assimilative capacities of ecosystems, and in a way that enhances the long-term resilience of the integrated socio-ecosystem.

"PANARCHY" AND ADAPTATION

> We are now in an era of transformation in which ecosystem management must build and maintain ecological resilience as well as the social flexibility needed to cope, innovate and adapt.
> —*C. S. Holling*[16]

Understanding and coping with change is at the heart of resilience thinking, but so far we have discussed change as if it were always random and unexpected. This is not the most interesting kind of change affecting complex systems. Researchers around the world have discovered that the most significant changes in natural systems generally follow a recurring pattern consisting of several phases. These can be described as rapid growth, consolidation and conservation, release (or "collapse"), and reorganization (see box 3.2). Each iteration of the cycle provides opportunities for innovation and recombination "experiments," thus enabling species and whole subsystems to adapt to both external and internal change. In short, the recurring cycles are inherently adaptive and provide a key to understanding the evolution of natural systems.

Significantly, adaptive cycles are virtually universal. They take place at every level within the overlapping/nested hierarchy of subsystems at scales ranging from a leaf to the ecosphere and over periods ranging from days to geological epochs. On the human side, they affect individuals, communities, and entire sociopolitical regions over periods from months to centuries. Researchers use the term "panarchy" (literally, "ruling

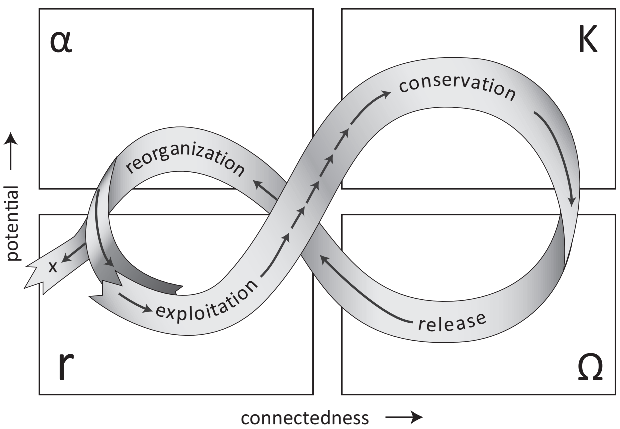
over everything") to describe this nested hierarchy, since it transcends scales in time and space and extends across numerous academic disciplines. The emphasis in panarchy theory is to discover the role of recurring dynamics in systems adaptation: "If we can understand these cycles, it seems possible to evaluate their contribution to sustainability and to identify the points at which a system is capable of accepting positive change, the points where it is vulnerable."[17]

RESILIENCE, PANARCHY, AND SUSTAINABILITY

If change is inevitable and resilience is necessary for systems stability, what can panarchy theory contribute to our quest for sustainability? Does it, in fact, suggest points for positive human intervention in the name of resilience, and can it avoid vulnerable configurations in at least some systems?

Recall that contemporary resource-management approaches typically attempt to maximize one or a few desirable systems components at the expense of other species and systems functions—think agricultural or forestry monoculture. Diversity plummets and functions are lost. The managed system becomes inflexibly brittle and vulnerable to unexpected external shocks. While apparently stable, the system's resilience

BOX 3.2
The Adaptive Cycle



A stylized representation of the four ecosystem functions (r, K, Ω, α) and the flow of events among them. The arrows show the speed of that flow in the cycle, where short, closely-spaced arrows indicate a slowly changing situation and long arrows indicate a rapidly changing situation. The cycle reflects changes in two properties: (1) y-axis—the potential that is inherent in the accumulated resources of biomass and nutrients; (2) x-axis—the degree of connectedness among controlling variables. Low connectedness is associated with diffuse elements loosely connected to each other whose behavior is dominated by outward relations and affected by outside variability. High connectedness is associated with aggregated elements whose behavior is dominated by inward relations among elements of the aggregates, relations that control or mediate the influence of external variability. The exit from the cycle indicated at the left of the figure suggests, in a stylized way, the stage where the potential can leak away and where a flip into a less productive and organized system is most likely.

Figure and caption reprinted with permission from L. H. Gunderson and C. S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington DC: Island Press, 2002), 34. Copyright © 2002 Island Press.

Exploitation and growth phase: The early phase in a new adaptive cycle is characterized by the establishment and rapid growth of the stronger opportunistic species (or new businesses) that have flooded in to take advantage of open ecological niches (or unexploited markets) and temporarily plentiful resources. All such "start-ups" are agile and flexible; they may explore numerous available niches or options. In the social domain, new societies or even nations can emerge. Initially, diversity and resilience are high but internal connectivity is low. As it develops, the system gradually creates a stable regime.

Conservation phase: This longest phase of the cycle is characterized by consolidation and accumulation and a change in the character of constituent species. The competitive advantage enjoyed by wasteful generalists/opportunists in the growth phase shifts to efficient specialists. Less aggressive competitors are repressed or eliminated and new entrants to the ecosystem (or market) find it difficult to establish themselves. In ecosystems, internal connectedness and stability increase (though over a narrow range of conditions) and growth slows. Diversity and resilience gradually decline as nutrients and biomass accumulate in a shrinking number of dominant species that compete for ever-scarcer resources. In the economy, establishment firms become complacently unresponsive to changing market conditions or emerging new technologies. Both types of systems become more rigidly homogeneous and monopolistic, which increases their vulnerability to unexpected shocks.

Release phase: "The longer the conservation phase persists, the smaller the shock needed to end it."[1] Subsequent "release" may happen in an instant. With resilience at a minimum, any number of factors—insect outbreaks, prolonged drought, wildfire—can destroy an existing ecosystem, releasing and dissipating stored energy and nutrients. All structure and organization may be lost in the collapse. In the economy, sharp changes in market conditions or new technologies can bring down major corporations or sectors. (For example, in 2007–2009 escalating oil prices and changing consumer preferences brought the North American auto sector to its knees; corruption, lax regulation, and the loss of investor confidence undermined financial markets and bankrupted many firms.)

Reorganization phase: The chaos of release creates numerous opportunities for novelty and experimentation. All options are theoretically open—the future path of the system is up for grabs. In ecosystems, abundant nutrients and access to sunlight create ideal conditions for opportunistic species. Invader species from distant ecosystems or novel combinations of existing organisms may become established and set the system on an unfamiliar course (as seems to have happened to the Atlantic cod ecosystem). In economies, new technologies and aggressive entrepreneurs can move in to fill niches left by failing firms. Often, however, conditions in this phase tend to produce a faithful repetition of the previous cycle. (Think about the U.S. government's trillion-dollar bailout of the financial sector and its rescue of the auto industry in 2008–2009.) In either case, events during the reorganization determine what species/corporations will ultimately dominate the subsequent growth phase.

1 Brian Walker and David Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Washington DC: Island Press, 2006), 77.

is minimal. In effect, this kind of management approach—aiming for maximum production in the most efficient way possible—creates systems that structurally most resemble the conservation phase of the adaptive cycle in near pre-collapse mode (box 3.2).

Now consider the form of contemporary global economic development. As previously noted (box 3.1), the emphasis here is on maximizing economic growth by exploiting the efficiency gains conferred by local specialization and global trade. This approach tends to maximize resource exploitation and material dissipation (pollution), both of which simplify ecosystems, undermine life-support functions, and erode systems resilience. On the socioeconomic side, the global economy becomes dominated by only a few global enterprises (and their numbers continue to shrink with each merger or acquisition). The sheer economic power of these monster corporations stifles meaningful competition and blocks new players from entering the market: Both local diversity and global diversity plummet. Meanwhile, the economy and society have become deeply dependent on a few declining energy sources (e.g., petroleum) and on energy-intensive systems (e.g., global transportation systems and even the Internet).

So structured, the entire human enterprise appears to be well into the "brittle" conservation phase of an adaptive cycle and highly vulnerable to external shocks.[18] Present globalization strategies represent nonresilience thinking at its best (i.e., "worst"). Perhaps we would do well to recall Joseph Tainter's observation: "What is perhaps most intriguing in the evolution of human societies is the regularity with which the pattern of increasing complexity is interrupted by collapse."[19]

For contrast, let's examine the structure and dynamics of the early growth phase of the adaptive cycle. Here species diversity is high, many organisms are flexible generalists, and the system is characterized by multiple redundancies. Stability and resilience are increasing and operate over a wide range of conditions. The system is least vulnerable to external shocks. Is this not more like what we are trying to achieve?

By understanding the changes in systems dynamics that accompany adaptive cycles in the panarchy we might begin to uncover clear guidelines for structuring sustainability. Remember, the goal is to maintain regional ecosystems and the economy in a structural configuration that promotes diversity and resilience in the face of inevitable shocks such as climate change and global economic turmoil. To achieve this, development strategies must abandon efficiency and maximization as primary goals in favor of social equity and ecological stability. Society should:

- Formally eschew continuous economic growth. The goal of economic activity should be to provide economic security for all within the productive capacity of regional and global ecosystems. This implies creation of a steady-state economy, one characterized by nongrowing throughput of energy and resources.
- Create economic planning regions on a humanly manageable spatial scale. The probability of being able to manage ecosystems and economies successfully decreases as geographic and systems scales increase.
- Manage regional ecosystems to maintain/increase species diversity, systems integrity, and optimal habitat patchiness for the species concerned. Inhibit development of the "conservation phase" of the adaptive cycle.
- Adopt the strong version of the constant-natural-capital-stocks-per-capita criterion for sustainability.[20]
- Strive to maintain economic diversity and multiple employment opportunities within every planning region. This implies balancing the contributions from primary resources and the manufacturing and service sectors. Stabilizing or increasing diversity may require limiting the size of individual enterprises and prohibiting mergers and acquisitions above a certain size.
- Invest in redundant energy systems with an emphasis on sustainable renewable solutions.

BOX 3.3

Fatal Adaptation (or "The Dark Side of Resilience" or "When Resilience Goes Rogue")

The life cycles of everything in the natural world, from cells through organisms to ecosystems, have been described as "never-ending adaptive cycles of growth, accumulation, restructuring and renewal."[1] While this implies recurring opportunities for novelty, particularly during "restructuring and renewal," near-faithful repetition of the previous cycle is more common in nature.

Not so with human-dominated socio-ecosystems. In the face of unwanted exogenous change, human ingenuity generally intervenes and can change the course of history. For example, industrial society's response to "perturbation" typically involves technological innovation or economic restructuring. This may irrevocably alter the character of relevant socio-ecosystems and extend the exploitation/growth and conservation phases of societal development.

Ironically, this characteristically human form of "resilience" is often triggered by problems created by *previous* extended periods of growth—we counter the depletion of soils by applying artificial fertilizers; with peak oil looming, we launch an (increasingly frantic) search for alternative sources of energy. Joseph Tainter argues that the human pattern of adaptation to serial challenges is actually the means by which societies become more complex and subsequently evolve.[2]

But there is a problem. "Adaptation through sequential depletion and substitution" uses up nonrenewable resource stocks and may even extinguish self-producing natural capital vital to long-term societal survival. Indeed, over several millennia we have witnessed the blossoming of numerous large-scale cultures and empires that eventually collapsed, never to reemerge in place.[3] Pre-agricultural societies may have experienced typically repeating adaptive cycles at small spatial and temporal scales, but grander, more technologically advanced societies can so degrade their socioeconomic systems that the "never-ending" cycle of growth to renewal may ignominiously grind to a halt.

This should be of particular concern today. Two hundred years of industrial technology have fueled the explosive growth of both human populations and per capita consumption; globalization—another *initially* adaptive strategy—has extended humanity's "scorched-earth" tactics to the entire planet (see box 3.1). The ecosphere is reeling and, if collapse does occur, it will effectively be global. There can be no "release" of critical assets, no fallback reserves, and no opportunity for subsequent reorganization and rebirth on a comparable scale. It seems that strategies that enhance the resilience of only the "socio-" part of vital socio-ecosystems will ultimately take us down.

Here's what Sir Fred Hoyle had to say on the matter:

> It has often been said that, if the human species fails to make a go of it here on Earth, some other species will take over the running.... [T]his is not correct. We have, or soon will have, exhausted the necessary physical prerequisites so far as this planet is concerned. With coal gone, oil gone, high-grade metallic ores gone, no species however competent can make the long climb from primitive conditions to high-level technology. [Civilization] is a one-shot affair. If we fail, this planetary system fails so far as intelligence is concerned.[4]

1 C. S. Holling, "Understanding the Complexity of Economic, Social and Ecological Systems," *Ecosystems* 4 (August 2001), 390–405.

2 Joseph Tainter, *The Collapse of Complex Societies* (Cambridge: Cambridge University Press, 1988).

3 Ibid.; Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York: Viking Penguin, 2005).

4 Fred Hoyle, *Of Men and Galaxies* (Seattle: University of Washington Press, 1964).

It is worth noting that such guidelines speak to the need to decrease regional dependence on imported resources (we are currently importing additional ecological carrying capacity to sustain local communities) and for the "relocalization" of economies. Resilient communities will develop policies that favor greater regional self-reliance, including mechanisms for import displacement when this is ecologically sound. Increased regional self-reliance would produce immediate economic and ecological savings in the form of reduced transportation costs, lower carbon dioxide emissions, and fewer processing and storage facilities. (A useful motto might be: "Trade if necessary, but not necessarily trade.")

Relocalization also brings ecological advantages. Local production for local consumption often has the potential to restore, at least partially, the integrity of local human-dominated ecosystems. For example, depositing urban organic compost on nearby farm- and forestland would close the nutrient cycles broken by the current spatial separation of rural ecosystems and urban populations.[21] It also doesn't hurt that people might once again begin to identify with nearby ecosystems from which they acquire much of their food and fiber. There can be no greater incentive for conservation than knowing one's life depends upon it.[22]

Getting to Global Sustainability

Obviously this entire resilience-oriented program flies in the face of conventional wisdom and current trends. But that is precisely the point—the present growth-bound global development paradigm is fatally flawed, inherently unsustainable, and on track for catastrophic implosion, from which there might not be a subsequent "reorganization" phase for billions of people (see box 3.3).

By contrast, if the suggested program were faithfully implemented region by region across the globe so that each planning region or country achieved a resiliently sustainable steady state, the aggregate effect would be global sustainability. Of course, anyone who reads the paper or watches the news will realize that nothing resembling such a resilience-based strategy is yet being seriously contemplated by any major government or mainstream development organization anywhere. On the positive side, while there may yet be no broad-scale applications, human society is gradually acquiring the knowledge necessary to reorganize itself to our long-term advantage. It is entirely possible to envision a human society functioning in relation to nature such that the resultant socio-ecosystems are resilient and therefore truly sustainable.

Endnotes

1 Even in the United States, life expectancy increased by thirty years during the twentieth century.

2 In effect, heavy resource exploitation implies the effective integration of the human enterprise with the corresponding ecosystem. Indeed, people are often the most ecologically significant consumer organism in managed ecosystems. We refer to the resultant hybrid system as a socio-ecosystem.

3 Brian Walker and David Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Washington DC: Island Press, 2006).

4 Julian Simon, “The State of Humanity: Steadily Improving,” *Cato Policy Report* (September/October 1995). Available at http://www.cato.org/pubs/policy_report/pr-so-js.html.

5 Albert A. Bartlett, “Forgotten Fundamentals of the Energy Crisis,” *American Journal of Physics* 46, no. 9 (1978), 876–888.

6 The now-discredited concept of “maximum sustainable yield” is a classic example of this equilibrium-oriented management approach.

7 C. S. Holling, Lance H. Gunderson, and Donald Ludwig, “In Quest of a Theory of Adaptive Change,” in *Panarchy: Understanding Transformations in Human and Natural Systems*, C. S. Holling and Lance H. Gunderson, eds. (Washington DC: Island Press, 2002), 6.

8 The capacity for continuous self-organization and self-production is sometimes called “autopoiesis.” Living systems from individual cells to the entire ecosphere are “autopoietic” systems.

9 Walker and Salt, *Resilience Thinking*, 8.

10 C. S. Holling, “Understanding the Complexity of Economic, Social and Ecological Systems,” *Ecosystems* 4 (August 2001), 390–405.

11 The domain over which key systems variables can safely range while maintaining specific systems characteristics is sometimes called a systems “regime.”

12 For example, mean global temperature may be lagging behind rising greenhouse gas levels by 20 to 60 years.

13 Consider the many freshwater lakes—once prized for sport fishing and other water-based recreation—that we have seen suddenly “flip” into a eutrophic state characterized by noxious algae, anoxic water, and dead fish. Decades of excess nutrient runoff from agriculture and municipal sewage plants can push a lake beyond hidden thresholds where the negative feedbacks that kept the lake “clean” are overwhelmed by positive feedbacks that drive it into an alternative undesirable (from the human perspective) stable regime.

14 Walker and Salt, *Resilience Thinking*, 9.

15 That said, we must recognize that not all systems adaptation and resilience is obviously beneficial to humans. The increasing resistance of crop pests to biocides and the increasing resistance of bacteria to antibiotics are examples of resilient adaptations that frustrate human purposes. Similarly, in human societies, the resistance of powerful vested interests to needed changes to the status quo frustrates sustainability planning.

16 Holling, “Understanding the Complexity of Economic, Social and Ecological Systems,” 404.

17 Ibid., 392.

18 Climate change is possibly one such shock. Interestingly, the phenomenon of human-induced climate change is an example of one level in the global hierarchy (the human enterprise, an intermediate-speed subsystem) “feeding up” and reconfiguring a higher level (the global climate, a slower subsystem).

19 Joseph Tainter, “Sustainability of Complex Societies,” *Futures* 27, no. 4 (May 1995), 397–407.

20 The “constant-capital-stocks criterion” for sustainability states that a society is sustainable if its wealth-producing assets per capita are adequate, and are constant or growing. There are two versions. Economists tend to prefer a “weak sustainability” version in which the aggregate dollar value of different forms of capital is maintained. This assumes, among other things, that natural capital and manufactured capital are substitutes and that there is no penalty associated with liquidating natural capital to acquire an equivalent or greater market value of manufactured capital. Ecologists and ecological economists prefer a “strong sustainability” version in which constant, adequate, per capita physical stocks of both natural capital and manufactured capital are maintained in separate accounts. Monetary commensurability is denied on grounds that some forms of natural capital are nonsubstitutable and that their loss would be irreversible and potentially catastrophic.

21 See the discussion on “night soil” in Herbert Girardet, *Cities, People, Planet: Liveable Cities for a Sustainable World* (Chichester, UK: Wiley-Academy, 2004).

22 Note that the guidelines are fully compatible with the well-developed bioregional philosophy of living as much as possible “in place” and could be used as a further argument in support of the contemporary relocalization movement.

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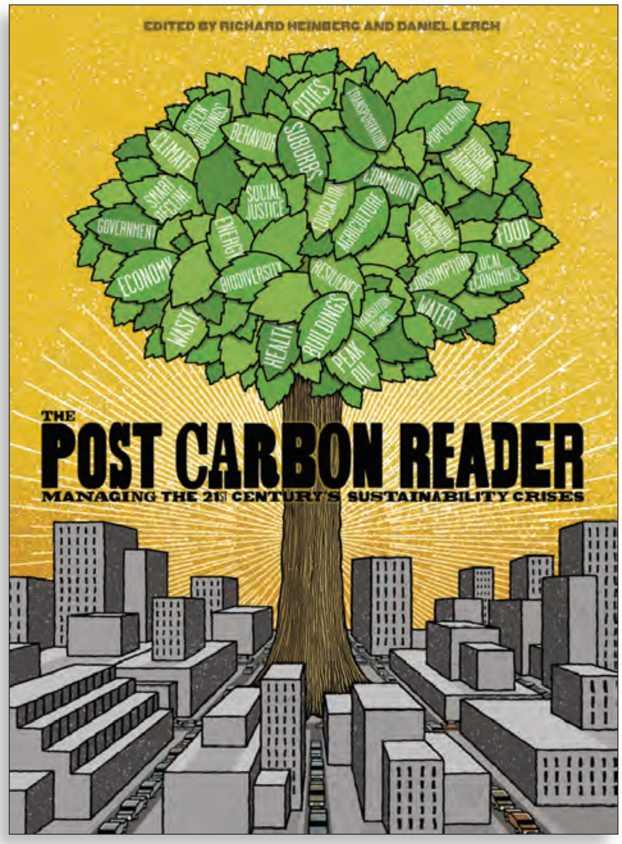

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