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Our panarchic future: a theory that explains the evolution of ecosystems may apply to civilizations as well--and it says we're approaching a critical phase.

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OUR PANARCHIC FUTURE

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A theory that explains the evolution of ecosystems may apply to civilizations as well-and it says we're approaching a critical phase

[Editor's note: The following article is adapted from The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization, by Thomas Homer-Dixon (copyright © Resource & Conflict Analysis, Inc.) and printed by permission of Island Press, Washington, D.C. (www.islandpress.org).]

Buzz Holling, one of the world's great ecologists, is a kind and gracious man, with a shock of white hair and a warm smile. Born in Toronto and educated at the University of Toronto and the University of British Columbia, he worked for many years as a research scientist for the government of Canada, where he pioneered the study of budworm infestations in the great spruce forests of New Brunswick. Later, as an academic researcher and eventually as director of the International Institute for Applied Systems Analysis in Austria, he created powerful mathematical models to explain the ecological phenomena he saw in the field. Using these models, he achieved major breakthroughs in understanding what makes complex systems of all kinds — from ecosystems to economic markets — adaptive and resilient.

Since the early 1970s, Holling's research has attracted attention in disciplines ranging from anthropology to economics. His papers have been distributed like samizdat through the Internet, and Holling himself has become something of a guru for an astonishing number of very smart people studying complex adaptive systems. Some of these researchers have coalesced into an international scientific community called the Resilience Alliance, with over a dozen participating institutions around the world. Although Holling is now retired from his last academic position at the University of Florida, he's still terrifically vigorous and focused on furthering the Resilience Alliance's work.

Holling and his colleagues call their ideas "panarchy theory" — after Pan, the ancient Greek god of nature. Together with anthropologist and historian Joseph Tainter's ideas on complexity and social collapse, this theory helps us see our world's tectonic stresses as part of a long-term global process of change and adaptation. It also illustrates the way catastrophe caused by such stresses could produce a surge of creativity leading to the renewal of our global civilization.

Dangerous Efficiency

Panarchy theory had its origins in Holling's meticulous observation of the ecology of forests. He noticed that healthy forests all have an adaptive cycle of growth, collapse, regeneration, and again growth. During the early part of the cycle's growth phase, the number of species and of individual plants and animals quickly increases, as organisms arrive to exploit all available ecological niches. The total biomass of these plants and animals grows, as does their accumulated residue of decay — for instance, the forest's trees get bigger, and as these trees and other plants and animals die, they rot to form an ever-thickening layer of humus in the soil. Also, the flows of energy, materials, and genetic information between the forest's organisms become steadily more numerous and complex. If we think of the ecosystem as a network, both the number of nodes in the network and the density of links between the nodes rise.

During this early phase of growth, the forest ecosystem is steadily accumulating capital. As its total mass grows, so does its quantity of nutrients, along with the amount of information in the genes of its increasingly varied plants and animals. Its organisms are also accumulating mutations in their genes that could be beneficial at some point in the future. And all these changes represent what Holling calls greater "potential" for novel and unexpected developments in the forest's future.

As the forest's growth continues, its components become more linked together — the ecosystem's "connectedness" goes up — and as this happens it evolves more ways of regulating itself and maintaining its stability. The forest develops, for example, a larger number of organisms that "fix" nitrogen — converting the element from its inert form in the air to forms that plants and animals can use — in the specific amounts and in the specific places needed. It becomes home to more worms, beetles, and bacteria that break down the complex organic molecules of rotting plants into useful nutrients. And it produces more negative feedback loops among its various components mat keep temperature, rainfall, and chemical concentrations within a range best suited to life in the forest.

Over time as the forest matures and passes into the late part of its growth phase, the mechanisms of self-regulation become highly diverse and finely tuned. Species and organisms are progressively more specialized and efficient in using the energy and nutrients available in their niche. Indeed, the whole forest becomes extremely efficient — in a sense, it effectively adapts to maximize the production of biomass from the flows of sunlight, water, and nutrients it gets from its environment. In the process, redundancies in the forest's ecological network — like multiple nitrogen fixers — are pruned away. New plants and animals find fewer niches to exploit, so the steady increase in diversity of species and organisms slows and may even decline.

This growth phase can't go on indefinitely. Holling implies — very much as Tainter argues in his theory — that the forest's ever-greater connectedness and efficiency eventually produce diminishing returns by reducing its capacity to cope with severe outside shocks. Essentially, the ecosystem becomes less resilient. The forest's interdependent trees, worms, beetles, and the like become so well adapted to a specific range of circumstances — and so well organized as an efficient and productive system-that when a shock pushes the forest far outside that range, it can't cope. Also, the forest's high connectedness helps any shock travel faster across the ecosystem. And finally, the forest's high efficiency makes it harder for it to realize its rising potential for novelty. For instance, the extra nutrients that the forest ecosystem has accumulated aren't easily available to new species and ecosystem processes because they're fully expropriated and controlled by existing plants and animals. Overall, men, the forest ecosystem becomes rigid and brittle. It becomes, as Holling says, "an accident waiting to happen."

So in the late part of the growth phase of any living system like a forest, three things are happening simultaneously: the system's potential for novelty is increasing, its connectedness and self-regulation are also increasing, but its overall resilience is falling. At this point in the life of a forest, a sudden event such as a windstorm, wildfire, insect outbreak, or drought can trigger the collapse of the whole ecosystem. The results, of course, can be dramatic — large tracts of beautiful forest can be obliterated. The ecosystem loses species and biomass and in the process much of its connectedness and selfregulation.

But the effects on the ecosystem's overall health may be very positive. A wildfire in a mature forest creates open spaces that allow new species to establish themselves and propagate; it destroys infestations of disease and insects; and it converts vegetation and accumulated debris into nutrients that can be used by plants and animals that reestablish themselves after die fire. The organisms that survive become much less dependent on specific, long-established relationships with each orner. Most important, collapse also liberates the ecosystem's enormous potential for creativity and allows for novel and unpredictable recombination of its elements. It's as if somebody threw the forest's remaining plants, animals, nutrients, energy flows, and genetic information into a gigantic mixing bowl and stirred. Once-marginal species can now capture and exploit newly released nutrients, and genetic mutations that were a bane to survival can now be a boon.

And because the system is suddenly far less interconnected and rigid, it's far more resilient to sudden shock. This is a perfect setting for the forest's plants and animals to experiment with new behaviors and relationships — a pollinator species like a bee or wasp will try gathering nectar from a type of flower it hadn't previously visited, or a carnivore might try killing and eating a different kind of prey. If such experiments fail, the damage is less likely to cascade across the entire system.

In these ways the forest ecosystem reorganizes and regenerates itself, quite possibly in a very new form. Put simply, the catastrophe of collapse allows for the birth of something new. And this cycle of growth, collapse, reorganization, and rebirth allows the forest to adapt over the long term to a constantly changing environment. "The adaptive cycle," Holling writes, "embraces two opposites: growth and stability on one hand, change and variety on the other." It's at once conserving and creative — a characteristic of all highly adaptive systems.

Holling and his colleagues use a three-dimensional image to represent the relationship between a system's rising potential and connectedness and its declining resilience. The shape looks like a distorted figure eight or infinity symbol floating in space. In the foreground is the growth phase — a curve that moves upward as the system's potential and connectedness increase. At the same time, the curve moves forward in threedimensional space — toward the observer — as the system's resilience declines. Holling and his colleagues call this part of the adaptive cycle the "front loop." It represents a process of incrementally rising complexity. At the top of this curve, the system collapses. Things then happen fast as the system descends into the "back loop," where it undergoes a rapid process of reorganization before beginning once more the slow process of growth.

Nested Cycles

There's one more essential part to Holling's theory. He argues that no given adaptive cycle exists in isolation. Rather, it's usually sandwiched between higher and lower adaptive cycles. For instance, above the forest's cycle is the larger and slowermoving cycle of the regional ecosystem, and above that, in turn, is the even slower cycle of global biogeochemical processes, where planetary flows of materials and elements — like carbon — can be measured in time spans of years, decades, or even millennia. Below the forest's adaptive cycle, on the other hand, are the smaller and faster cycles of sub-ecosystems that encompass, for instance, particular hillsides or streams. In fact, adaptive cycles can be found all the way down to the level of bacteria in the soil, where the smallest and fastest cycles of all are found. Here things happen on a tiny scale of millimeters or even microns, and they can take place in minutes or even seconds. So the entire hierarchy of adaptive cycles — what Holling and his colleagues call a panarchy — spans a scale in space from soil bacteria to the entire planet and a scale in time from seconds to geologic epochs.

This brings us to the most important point of all for our purposes: the cycles operating above and below play an important role in the forest's own adaptive cycle. The higher and slower-moving cycles provide stability and resources that buffer the forest from shocks and help it recover from collapse. A forest may be hit by wildfire, for example, but as long as the climate pattern across the larger region that encompasses the forest remains constant and the rainfall adequate, the forest should regenerate. Meanwhile, the lower and faster-moving cycles are a source of novelty, experimentation, and information. Together, the higher and lower cycles help keep the forest's collapse, when it occurs, from being truly catastrophic. But for this healthy arrangement to work, these various adaptive cycles must be at different points along that figure-eight loop. In particular, they mustn't all peak at the top of their growth phases simultaneously. If they do — if they are "aligned at the same phase of vulnerability," to use Holling's phrase — they will together produce a much more devastating collapse, and recovery will take far longer, if it happens at all. Should a wildfire hit a forest at the same time as the regional climate cycle enters a drought phase, the forest might never regenerate.

Panarchy theory helps us understand how complex systems of all kinds, including social systems, evolve and adapt. Of course, it shares similarities with other theories of adaptation and change. Its core idea — that systems naturally grow, become more brittle, collapse, and then renew themselves in an endless cycle — recurs repeatedly in literature, philosophy, religion, and studies of human history, as well as in the natural and social sciences. But Holling has done much more than just restate this old idea. He has made it far more precise, powerful, and useful by distinguishing between potential, connectivity, and resilience; by identifying variations in the system's pace of change as it moves through its cycle; and by describing the roles of adjacent cycles in the grand hierarchy of cycles.

Holling embodies something truly rare: the kind of wisdom that comes when an enormously creative, perceptive, and courageous mind spends a half-century studying a phenomenon and distilling its essential patterns. In a conversation with him not long ago, I encouraged him to expand on many aspects of panarchy theory, filling gaps in my understanding and giving me nuance and perspective that only he could provide. As we came to the end of our conversation, I asked him a question that had been on my mind since our first meeting a year before, when he'd been adamant that humanity is at grave risk.

"Why do you feel die world is verging on some kind of systemic crisis?"

"There are three reasons," he answered. "First, over the years my understanding of the adaptive cycle has improved, and I've also come to better understand how multiple adaptive cycles can be nested together — from small to large — to create a panarchy. I now . believe that this theory tells us something quite general about the way complex systems, not just ecological systems, change over time. And collapse is usually part of the story.

"Second, I think rapidly rising connectivity within global systems — both economic and technological — increases the risk of deep collapse. That's a collapse that cascades across adaptive cycles — a kind of pancaking implosion of the entire system as higherlevel adaptive cycles collapse, which causes progressive collapse at lower levels."

"A bit like the implosion of the World Trade Center towers," I offered, "where the weight of the upper floors smashed through the lower floors like a pile driver."

"Yes, but in a highly connected panarchy, the collapse doesn't have to start at the top. It can be triggered at the microlevel or the macrolevel or somewhere in between. It's the tight interlinking of the adaptive cycles across the whole system — from the individual right up to the level of the global economy and even Earth's biosphere — that's particularly dangerous because it increases the likelihood that many of the cycles will become synchronized and peak together. And if this happens, they'll reinforce each other's collapse."

"The third reason," he continued, "is the rise of megaterrorism — the increasing risk of attacks that will kill huge numbers of people and produce major disruptions in world systems. I'm not sure why megaterrorism has become more likely now. I suppose it's partly a result of technological changes and the rise of particularly virulent kinds of fundamentalism. But I do know that in a tightly connected world where vulnerabilities are aligned, such attacks could trigger deep collapse — and that's particularly worrisome.

"This is a moment of great volatility and instability in the world system. We need urgently to do what we can to avoid deep collapse. We also need to figure out how to exploit the opportunity provided by crisis and collapse when they occur, because some kind of systemic breakdown is now almost certain."

We can see die danger of the tectonic stresses in a new light if we think of humankind — including all our interactions with each other and with nature and all the flows of materials, energy, and information through our societies and technologies — as one immense social-ecological system. As this grand system we've created and live within moves up the growth phase of its adaptive cycle, it's accumulating potential in the form of people's skills and economic wealth. It's also becoming more connected, regulated, and efficient — and ultimately less resilient. And finally, it's becoming steadily more complex, which means it's moving further and further from thermodynamic equilibrium. We need ever-larger inputs of high-quality energy to maintain this complexity. In die meantime, internal tectonic stresses — including worsening scarcity of our best source of high-quality energy, conventional oil — are building slowly but steadily.

So we're overextending the growth phase of our global adaptive cycle. We'll reach the top of this cycle when we're no longer able to regulate or control the stresses building deep inside the global system. Then we'll get earthquakelike events that will cause the system's breakdown and simplification as it moves closer to thermodynamic equilibrium.

Panarchy theory also helps us better understand another critically important phenomenon: the denial that prevents us from seeing the dangers we face. Our explanations of the world around us — whether of Earth's place in the cosmos or of the workings of our economy — move through their own adaptive cycles. When a favorite explanation encounters contradictory evidence, we make an ad hoc adjustment to it to account for this evidence — just like Ptolemy added epicycles to his explanation of the planets' movements. In the process, our explanation moves through something akin to a growth phase: it becomes progressively more complex, cumbersome, and rigid; it loses resilience; and it's ripe for collapse should another, better, theory come along.

We often invest enormous mental energy to maintain a perspective on the world that's at variance with reality — that's far from intellectual equilibrium, so to speak. But today bits of anomalous evidence — from data on the melting of Greenland's ice cap to reports of steadily falling discovery of new oil fields — are piling up around us.

Lessons from Rome…

For over a millennium in Western culture, Rome's collapse has been an emblem of social catastrophe, one often used as a cudgel in political debate. When people don't approve of a particular social, political, or economic trend, they'll often assert that it caused Rome's demise. So explanations have proliferated. In 1984 the German historian Alexander Demandt listed more than 200 different explanations for Rome's fall that he found in the historical literature since 1600 — from epidemics, plutocracy, and the absence of character to vainglory.

Perhaps it's rash, then, to add another one to the list. Still, recent work by archaeologists, economic historians, and complexity theorists gives fresh insight into what happened. And their story, which has immense relevance to our situation today, comes down to this.

Because energy is a society's master resource, when Rome exhausted its energy subsidies from its conquests — when it had to move, in other words, from high energy-return-oninvestment (EROI) sources of energy to low-EROI sources — it faced a critical transition. And, at least in the Western part of the empire, it didn't make this transition successfully. It couldn't sustain the cost and complexity of its far-flung army, ballooning civil service, hungry and restless cities, elaborate information flows, and intricate irrigation systems. Not that it didn't try. Rome's prodigious effort to save itself by putting in place a system to aggressively manage its energy problem was simultaneously one of history's greatest triumphs and tragedies. It was a triumph because, for a while at least, the effort reversed what seemed like the empire's inexorable decline; but it was ultimately a tragedy because it didn't address the empire's underlying problem — complexity too great for a food-based energy system — and was thus bound to fail.

The western Roman empire couldn't make the transition from high-EROI to low-EROI sources of energy. Today, our societies are headed toward a similar transition as oil becomes harder to find. Sometime in the 1960s the United States crossed a critical threshold when its EROI for domestic petroleum extraction started to fall, and it's likely that since then just about every other oil-producing region in the world has crossed the same threshold (often it takes a while for data to show clearly that the threshold has been crossed). Very few people — certainly not our society's leaders — grasp the significance of this change, yet it's of epochal importance. It marks the beginning of a shift from our modern industrial civilization to some other kind of civilization.

We can't yet say what form this new civilization will take, but we can be fairly certain that compared with our experience over the century and a half since the industrial revolution, energy will become far more costly as nonconventional and renewable sources replace cheap oil. The price rise won't be steady and linear: we'll see sharp spikes and dips as the global economy tries to adjust. Even an average increase in real energy costs of just 2.5 percent each year — a rate we've consistently exceeded in recent years — will compound into a tenfold increase in a century.

Can we get through this transition wisely and safely? Not if we refuse to understand its implications and simply continue what we're doing now. In Buzz Holling's terms, we're busily extending the growth phase of the adaptive cycle of our planetary economic, ecological, and social system. In the process, this planetary system is becoming steadily more complex, connected, efficient, and regulated. Eventually it will become less resilient; it may, in fact, have already started to lose resilience.

A number of factors drive these changes. First, the desperate need of companies, economies, and societies to maximize performance and productivity forces them to steadily boost their organizational and technological complexity, their internal efficiency and regulation, and their speed of production and transport of materials, energy, and information. Also, as the world economy expands relative to the size of Earth's resource base and biosphere, we have, to use resources and energy far more efficiently and manage our interactions with nature with ever greater care — and this means progressively more elaborate technologies, procedures, regulations, and institutions. Based on current trends, global output of goods and services will quadruple from US$60 to $240 trillion (in 2005 dollars) by 2050. If we're going to keep such a gargantuan economy humming — and if we're going to avoid simultaneously wrecking the planet's environment — we'll need everything from high-tech energy and water conservation programs to huge bureaucracies that find and punish the.

people and companies that emit too much carbon dioxide. And finally, as our EROI declines in coming decades, we'll need far more sophisticated technologies and organizations to scavenge small pockets of oil from all over the world and to pull together lower-quality energy from a myriad of solar, wind, and geothermal generating plants.

In short, in coming decades our resource and environmental problems will become progressively harder to solve; our companies, organizations, and societies will therefore have to become steadily more complex to produce good solutions; and the solutions they produce — whether technological or institutional — will have to be more complex too.

…and from Holland

Today's Holland gives us a hint of what mis future might be like. One of the world's most crowded countries, Holland has a heavily industrialized, energy-intensive, high-consumption economy, and its people must constantly fight back the sea to survive on their small patch of territory — much of it indeed reclaimed from the sea. Over the centuries, the Dutch have responded by putting in place astonishingly complex systems of technology and social regulation. These have included block-by-block urban residential committees to prevent flooding, detailed laws to maximize efficient use of land, and of course an intricate system of dikes, canals, and pumping stations. As Holland has become progressively wealthier, more crowded, and more hemmed in by resource and environmental pressures, the regulations and technologies have become steadily more intricate and costly.

But if we end up with a global society and economy like Holland's, would mat really be so bad? After all, the Dutch live very well. Sadly, even the enormous complexity of today's Holland won't be remotely adequate for the host of planetary challenges we're going to have to address soon, like climate change and worsening shortages of high-quality energy. We'll have to create a global society that I've come to call "Holland times 10," with vastly more sophisticated, pervasive, and expensive rules and regulatory institutions than, anything the Dutch live with today. Do we really want such a future for ourselves and our children?

And even if we do, can we really create it? First of all, Holland is in some ways an inadequate example. It's a small, ethnically homogeneous society with relatively low economic inequality, a deeply rooted culture of collaboration, and a citizenry that's receptive to social policies intended to change people's behaviors. These are hardly features of our world as a whole. Also, today's Holland maintains its comfortable lifestyle by importing energy, food, and natural resources from far beyond its boundaries, and by expelling much of its wastes, such as its carbon dioxide, outside its boundaries too — Holland's carbon dioxide ends up traveling in the atmosphere around the planet.

Humanity as a whole, though, can't get its resources or expel its pollution beyond Earth's boundaries.

More important, as our global social-ecological system moves through the growth phase of its adaptive cycle — toward a Holland-times-10 future — it's losing resilience. Capitalism's constant pressure on companies to maximize efficiency tightens links between producers and suppliers; reduces slack, buffering, and redundancy; and so makes cascading failures more likely and damaging. As well, capitalism's pressure on people to be more productive and efficient drives them to acquire hyperspecialized skills and knowledge, which means they become less autonomous, more dependent on other specialized people and technologies, and ultimately more vulnerable to shocks (remember how most Americans were so ill equipped to deal with the 2003 blackout). Meanwhile, worsening damage to the local and regional natural environment in many poor countries is fraying ecological networks and undermining economies and political stability. And finally pressure is increasing within both rich and poor societies too — from tectonic stresses like demographic imbalance, growth of megacities, and widening income gaps.

All these factors are creating an overload condition just at the moment when we're entering an epochal shift from high-EROI to low-EROI sources of energy. Because it takes energy to create and maintain complexity and order, and because energy will become steadily more expensive, we'll find it steadily harder to implement complex solutions to our complex problems.

Indeed, in a world of far higher energy costs, a Holland-times-10 global system is likely impossible. Even today's globalized economy won't be viable, because it takes too much energy to keep it running. As energy prices rise, we'll first see cutbacks on long-distance travel and trade. Instead of becoming increasingly "flat" as barriers to commerce and economic integration disappear — as some commentators, such as the New York Times columnist Thomas Friedman, suggest — the world will become more regionalized and even hierarchical because manufacturing, commerce, and political power will shift to countries with relatively good access to energy. Eventually those of us in rich countries will have to change many things in our societies and daily lives — not just the machines we use to produce and consume energy but also the work we do, our entertainment and leisure activities, how much we travel in cars and airplanes, our financial systems, the design of our cities, and the ways we produce our food (because our current agricultural practices consume a huge amount of energy).

The growth phase we're in may seem like a natural and permanent state of affairs — and our world's rising complexity, connectedness, efficiency, and regulation may seem relentless and unstoppable — but ultimately it isn't sustainable. Still, we find it impossible to get off this upward escalator because our chronic state of denial about the seriousness of our situation — aided and abetted by powerful special interests that benefit from the status quo — keeps us from really seeing what's happening or really considering other paths our world might follow. Radically different futures are beyond imagining. So we stay trapped on a path that takes us toward major breakdown.

The longer a system is "locked in" to its growth phase, says Buzz Holling, "the greater its vulnerability and the bigger and more dramatic its collapse will be." If the growth phase goes on for loo long, "deep collapse" — something like synchronous failure — eventually occurs. Collapse in this case is so catastrophic and cascades across so many physical and social boundaries that the system's ability to regenerate itself is lost. [A] forest-fire shows how mis happens: if too much tinder-dry debris has accumulated, the fire becomes too hot, which destroys the seeds that could be the source of the forest's rebirth.

Holling minks the world is reaching "a stage of vulnerability that could trigger a rare and major 'pulse' of social transformation." Humankind has experienced only three or four such pulses during its entire evolution, including the transition from hunter-gatherer communities to agricultural settlement, the industrial revolution, and the recent global communications revolution. Today another pulse is about to begin. "The immense destruction that a new pulse signals is both frightening and creative," he writes. "The only way to approach such a period, in which uncertainty is very large and one cannot predict what the future holds, is not to predict, but to experiment and act inventively and exuberantly via diverse adventures in living."

For more information about issues raised in this story, visit www.worldwatch.org/ww/panarchic.

DIAGRAM

PHOTO (COLOR): The Trail Creek Fire, Yellowstone National Park, 1974.

PHOTO (COLOR): Arnica blooming one year after the Divide Fire, Yellowstone National Park, 1975.

PHOTO (COLOR): Tapped out: the oil patch in Long Beach, California, May 1923.

PHOTO (COLOR): Dried up: the Roman aqueduct Pont du Gard, in southern France. It once delivered 20,000 cubic meters of water to Nîmes daily.

PHOTO (COLOR): The inefficiency of too much efficiency: This factory farm in Deurne, Holland, because it was within three kilometers of one where autbreak of bird flu occurred, was forced to gas all of its 90,000 chickens as a precautionary measure.

PHOTO (COLOR)

PHOTO (COLOR)

PHOTO (COLOR)

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