

Perspective

From Complex Regions to Complex Worlds

[C. S. Holling](#)

ABSTRACT. Panarchy focuses on ecological and social systems that change abruptly. Panarchy is the process by which they grow, adapt, transform, and, in the end, collapse. These stages occur at different scales. The back loop of such changes is a critical time and presents critical opportunities for experiment and learning. It is when uncertainties arise and when resilience is tested and established. We now see changes on a global scale that suggest that we are in such a back loop. This article assesses the possibility of using the ideas that are central to panarchy, developed on a regional scale, to help explain the changes that are being brought about on a global scale by the Internet and by climate, economic, and geopolitical changes.

INTRODUCTION

For me, 2001 was a pivotal year. First came the submission of our book *Panarchy: Understanding Transformations in Human and Natural Systems* to the publisher. *Panarchy* presents theory and examples to explain why complex living systems create and also benefit from crisis. Then on September 11 came the terrorist attacks on the United States: the two Trade Center buildings, the Pentagon, and unsuccessfully, the Congress or White House. Those events represented a huge financial, military, and governmental attack that has since spawned both conflicting and supportive responses from governments. It launched the world on a journey whose path is unpredictable and unknown. It turned the United States government from an inward reaction of political ideology to an outward reaction of governmental, industrial, and military power. It has taken me a year and a half to begin to understand how panarchy, which arose from a regional focus, can perhaps explain and offer actions for what is a global, geopolitical phenomenon. This paper is the result.

Panarchy is an odd name, but one that is meant to capture the way living systems both persist and innovate at the same time. It shows how fast and slow, small and big events and processes can transform ecosystems and organisms through evolution, or transform humans and their societies through transformational learning or the chance for learning. I draw a distinction between transformation and other types of systemic change. Transformation occurs when

the self-organizing interaction between structure and processes become qualitatively different. The central question (B. H. Walker, C. S. Holling, S. R. Carpenter, and A. S. Kinzig, *unpublished manuscript*) is: What factors contribute to transformation that make it different from, and more rare than, change?

The multiauthored book describing the integrative nature of panarchy (Gunderson and Holling 2002) is partly a culmination of 50 yr of my own research, together with the work of a fine group of friends and colleagues in the Resilience Project. During that project, my ideas expanded and grew as they interacted with the ideas of ecologists, economists, social scientists, and mathematicians, all of whom were co-authors of *Panarchy*. It was a process of mutual, creative discovery that then turned personal for each of us.

For me, over those 50 yr the old notion of stable ecological systems embedded in the equilibrium images of Lotka-Volterra equations moved to that of resilience and multistable states (Holling 1973, Carpenter 2000), then to cycles of adaptive change in which persistence and novelty intertwined (Holling 1986), then to nested sets of such cycles in hierarchies of diversity covering centimeters to hundreds of kilometers and days to millennia (Holling 1992), and finally to the transformations that can cascade up the scales, with small, fast events affecting big, slow ones (Holling et al. 2002). Self-organization and natural selection jointly flourish and interact as a new way to view evolution (Levin 1999). In the sciences of

biological evolution, that combination can often be viewed as either an obscure or an excessive representation. However, it is suggestive and provocative, and that has particular value at times of deep change.

Because we were already dealing with a certain amount of jargon, we decided to go “whole hog” and invent the term “panarchy” for these ideas, by drawing on the mischievous Greek god Pan, the paradoxical spirit of nature. We joined the idea of Pan to the dynamic reality of hierarchies across scales, in which nature self-organizes lumps of living stuff on a more continuous physical template described by power laws. Physics defines the attributes of the power law. Biology self-organizes concentrations of opportunity and of species along the power law relation. Part of that organization is maintained by diversity within a scale and across scales (Peterson et al. 1998, Walker et al. 1999, Elmqvist et al. 2003), a uniquely panarchical representation of the role of diversity in maintaining a sustainable system. For ecosystems and landscapes, all this is arranged over an interactive scale from centimeters and days to hundreds of kilometers and millennia. Nothing is static: all components flip from quiet to noise, from collapse to renewal. Transformation is not easy and gradual. It is tough and abrupt.

The technical puzzles that I had accumulated over the years were resolved. In addition, the fewer but deeper and more intriguing paradoxes that I had experienced turned out to provide the foundation for a new understanding of sustainability. Those paradoxes did not emerge in my science, but did appear in the organizations I became part of; their origins were not in science, but in human experience. In each case, the organization had been newly created to capitalize on recent understanding, scales of perception, and integrative methods. It was a creation of history made by politically sensitive individuals who saw value in combining integrative scholarship within a context of current politics. Each made large advances toward the understanding of the critical attributes of complex systems and triggered extensions of collaboration among scholars of different disciplines and nations. However, as time passed, they all became less responsive to new opportunities.

I at last understood why, ultimately, the International Institute of Applied Systems Analysis (IIASA), Austria, could only grudgingly and partially change

and had to reduce and stabilize in a changing political world. Why the Institute of Resource Ecology at the University of British Columbia closed after great successes and despite huge opportunities. Why the University of Florida could establish only a partial “horizontal” College of Natural Resources to integrate disciplines across a wide spectrum, a college that became isolated despite considerable faculty support and trivial costs. Why Everglades restoration has such an extraordinary cost and distorted history, but momentarily happy present. Each of these institutions was, at different stages, a frustrating, fun, and challenging place for change and transformation embedded in panarchies that both encouraged novelty at some scales and fought it at others.

The Santa Fe Institute is another such place where a group of physicists, biologists, and computer specialists created both a new organization and a new field of enquiry in complex systems. Novelty, persistence, and evolution were all grist for the mill. It now is trying to restructure in an effort to recapture some of the original magic that has become partially lost in its own traditions. They are and were all rare and wonderful places for learning and experiment whose benefits then moved elsewhere. That is a big lesson: that major learned benefits need not, and generally do not, stay in the place where they were created. However, they flourish elsewhere. Can we facilitate that spread? Can they return? That is the kind of globalization that we want to encourage.

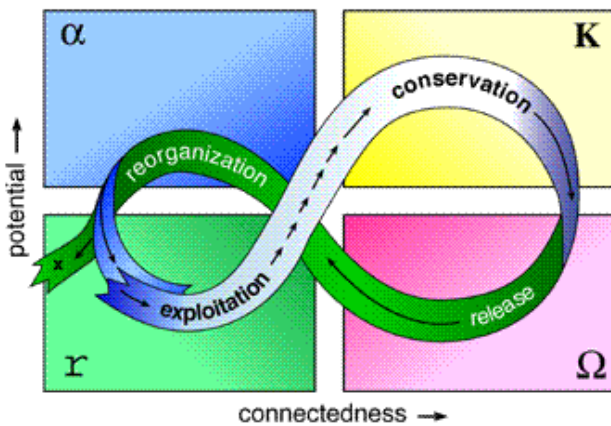
It seemed to become clear why and how persistence and extinction, growth and constancy, evolution and collapse intertwined to form a panarchy of adaptive cycles across scales. Hierarchy and adaptive cycles can combine to make healthy systems over scales from the individual to the planet and from days to centuries.

The panarchy shows that we benefit from local inventions that create larger opportunity while abstaining from those that destabilize because of their nature or excessive exuberance. When innovation occurs, we can sense its fate. When collapse looms, we can judge its likelihood. Plus, the timing and kind of responses to this swinging, turbulent process can be designed as an act of strategic decision. Sustainability both conserves and creates. So does biological evolution.

A BRIEF SUMMARY OF DISCOVERIES

The book *Panarchy: Understanding Transformations in Human and Natural Systems* (Gunderson and Holling 2002) describes our efforts to integrate theories and examples from ecology, economics, and social systems. It started with the results of decades of examination of ecosystems and the effects of management on their ecological and social components. That led to an image of change that recognized, across all examples in living systems, the existence, at some scale or scales from cell to biome, of the four principal phases that the elements of a system can cycle through: 1) entrepreneurial exploitation (r), organizational consolidation (K), creative destruction (Ω), and re- or destructuring (α). A stylized example is shown in Fig. 1. When the final, third axis of resilience is added, the diagram appears as in Fig. 2.

Fig. 1. A stylized representation of the four system functions and the flow of events among them (from Gunderson and Holling 2002).

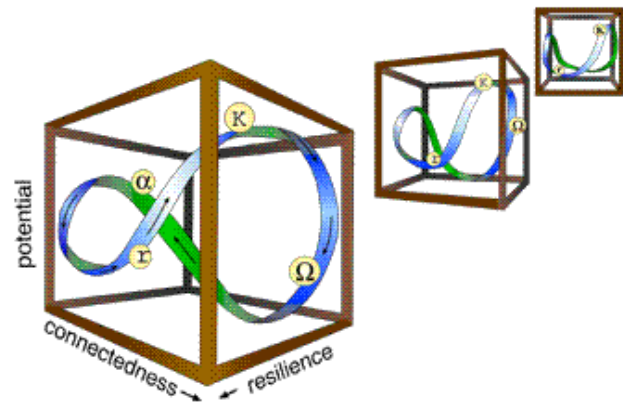


For an ecosystem such as a forest, think of the century- or centuries-long cycle of succession and growth from pioneer species (r) to climax species (K) followed by major disturbances such as fire, storm, or pest (Ω). Such disturbances occur as wealth accumulates and the system becomes gradually less resilient, i.e., more vulnerable. As a consequence, a disturbance is created to release accumulated nutrients and biomass and reorganize them into the start of a new cycle (α). That reorganization can then exploit the novelty that accumulates but is resisted or lies latent during the

forward loop. For a wetland like the Everglades, think of a 50-yr succession from open pond to floating and suspended vegetation, to accumulating peat, to sawgrass, again followed by a major disturbance and a reorganization of the cycle.

Each phase of those cycles creates the condition for the next phase. A pattern of two phases of growth is generated, followed by two phases of reorganization. The first two form a familiar, slow, fairly predictable pattern of growth called the “forward loop”; the second two constitute a less familiar, unpredictable, and, in ecosystems, more rapid “back loop” of reorganization.

Fig. 2. Resilience is another dimension of the adaptive cycle and, when added, shows that the figure-eight shape in Fig. 1 is seen as the consequence of a two-dimensional projection of a three-dimensional object (from Gunderson and Holling 2002)

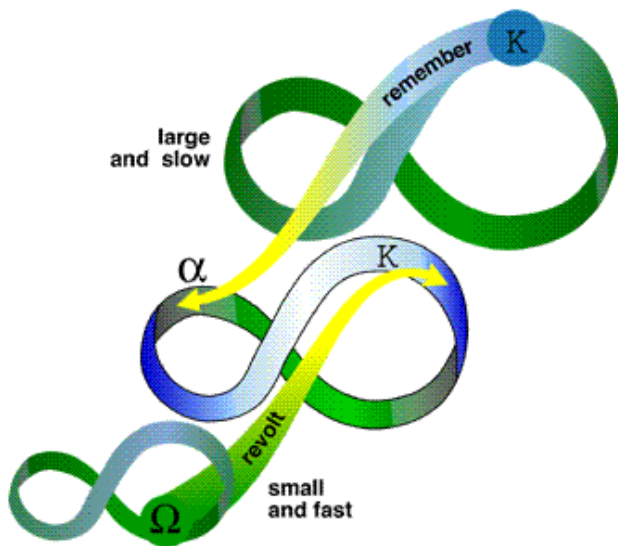


It is the two together that make the cycle adaptive. Novel elements can accumulate, largely unexpressed, during the forward loop. Then, in the back loop, they become the seeds for the novel combinations that launch the next cycle. However, the ecosystem cycle is embedded in a set of those cycles that cross scales in space and time from leaves, to trees, to patches, to stands, to forests, to biomes.

Finally, an important aspect of the adaptive cycle concept lies in the “pan” part of the panarchy, i.e., the cross-scale effects (Holling et al. 2002). That is, adaptive cycles in ecosystems occur in scales ranging from leaves to biomes in a panarchy of increasing scale from centimeters and days to hundreds of

kilometers and millennia. The structures along that hierarchy affect one another by opening up the possibility of the appearance of small-scale novelty during a back loop, followed by a cascade to larger scales. At the same time, persistence is encouraged by the memory of large-scale properties such as seed stores, biotic legacies, and institutional structures that influence the renewal of a smaller-scale cycle as suggested in Fig. 3.

Fig. 3. Also from Gunderson and Holling (2002), key connections between three levels of a panarchy, showing when small and fast cycles can affect larger and slower ones (revolt) or when large and slow ones can control the renewal of smaller and faster ones (memory).



Specifically, back-loop reorganization at one smaller scale can trigger changes at the larger, slower scales above. That is when novelty can be generated and sustained. At the same time, organizational consolidation at higher scales can provide a “memory” that influences the recovery of system dynamics at finer scales below. That is what sustains the repetition of adaptive cycles (Holling et al. 1998).

Those adaptive cycles and their relationships are not limited to the dynamics of ecosystems. I see them even in my own life. I happen to have had a pattern of 7- to 10-yr cycles of unplanned intellectual growth, frustration, and renewal that has been both great fun and provided a great sense of discovery. Westley (2002) describes her interview of an outstanding

resource manager in Wisconsin, showing how his successes and failures were very much part of the phases of his own personal cycle of change, which involved interorganizational groups, formal organizations, and politics. His plans and interventions both paced the vulnerability in each cycle of that hierarchy of cycles and, in some instances, created the vulnerability needed for change.

Similar cycles also occur in societies in which slow and fast, big and small structures interact. For institutions, Ostrom (1990) calls them operational rules, collective choice rules, and constitutional rules, each of which has different speeds of function, scale, and generality of relevance. For Whitaker (1987), those three structures in economies are fast individual preferences, slower and larger markets, and still more conservative and extensive social institutions. Westley (1995) sees decision making in human societies working through processes of allocation within social norms and cultural myths. Again, these three occur at distinct scales, and interactions among them involve the same processes of revolt and memory that can, paradoxically, both sustain and innovate. Old resilience colleagues Berkes in northern Canada, Folke in Sweden, and Gadgil in India (Berkes et al. 1995), see knowledge systems persisting and adapting in endemic societies within structures of local knowledge, potentially modified by management practice, within a larger world view. Each of those sets of triplets, together with those that relate to ecosystems, could be represented as specific system labels in Fig. 3.

Now all that is well structured, but it appears static. Where are the dynamics? Where do the transformation and persistence arise? Those are the elements that challenge every part of our lives, from the individual to the set of nations, and concern not only questions of growth but also questions of collapse.

Growth is important, but even more so are the forces in a healthy system that dominate during episodes when growth is halted or reversed, when deep uncertainty explodes, or when several alternative futures are unexpectedly perceived. Suddenly, the resulting unpredictability stifles informed action or triggers ignorant reaction. It is a time of back-loop crisis, but also of opportunity. During a back loop, unexpected interactions can occur among previously separate properties that can then nucleate an inherently novel and unexpected focus for future good or ill in the next cycle.

At such times, the future can also be suddenly shaped by external events such as those we now anticipate globally from slowly changing climate, from entrants of invasive species, from surprising diseases such as AIDS and SARS, from human immigrants driven by geopolitical changes, or from unexpected terrorist events. Such apparently external events can launch a path of future development along an unpredictable course. During such times, uncertainty is high, control is weakened and confused, and unpredictability is great. At the same time, space is created for reorganization and innovation. It is therefore also a time when individual cells, individual organisms, or individual people have the greatest chance to influence events. In societies, there is opportunity for exploratory experiment if the experiments are designed to have low costs of failure. The future can then be mapped by experiments that fail and succeed, rather than by long-term plans. It is the time when a Gandhi or a Hitler can use the events of the past to transform the future for great good or great ill.

In a biological, evolutionary setting, it is a time in which mammals can replace dinosaurs as the dominant life-form. The back loop is the time of the "Long Now" (Brand 1999), when each of us must become aware that he or she is a participant.

This is the contention of the editors of another book of the Resilience Project (Berkes et al. 2004). In the specific social and ecological systems they describe, the essence of sustainability is defined by processes that evolved during the back loop, i.e., processes that respond to novelty, memory, and instability. They reverse existing traditions of exploration and analysis by focusing on the back loop of collapse and reorganization, rather than on the front loop of growth and predictability. They therefore focus on foundations for change and on forces of evolution from biology, ecology, society, and culture.

I came to these conclusions in a process that mixed alternate periods of working on theory with more applied work. Each period persisted on its own for a time and generated ideas that were resolved by the other, for a time. Carl Walters was my partner, friend, and engaging provocateur for the fundamental applied work. This work led to constructive ways to engage colleagues and stakeholders in the novel analysis and synthesis of systems and issues (Holling and Chambers 1973). That has led to deep programs of specific discovery (e.g., Walker and Janssen 2002) and

has launched a broad collaborative study and the design of regional systems by the [Resilience Alliance](#) (Walker et al. 2002). Those dips into application, too, covered a fairly long period of about 35 yr and were launched by the invention of Adaptive Management, which, in a variety of forms, has become important in regional-scale management internationally. That progress in application and its connections with developments in theory and method has been summarized in a sequence of books (Holling 1978, Walters 1986, Lee 1993, Gunderson et al. 1995).

However, all these studies were regional in character. That is, they all emerged from places in which people, governments, and ecosystems were closely related. Examples include forest management in New Brunswick; fisheries management and recreational development in British Columbia; the progression of alpine villages in Austria; rangeland development in Zimbabwe; and wetlands, city, and agricultural development for the Everglades of Florida. All these, plus others, were chosen with colleagues simply because they were there, not because they covered a spectrum of politics or environmental conditions or economic developmental stages. Nevertheless, they did; all of them were places made timely because they faced or were already embedded in a back loop of change, and consequently open to fresh exploration and imagination. They were, therefore, places in which individuals could discover deep insights collaboratively.

However, can panarchy serve as a framework for thought followed by action in a potential phase of geopolitical transformation post-September 11, 2001? Not just regional change, but global and international? Are we in another period of change like the ones we experienced in the 1930s and 1940s? Are we in a "deep back loop" that presents the same opportunities and crises as the regional back-loop studies that we have described?

FROM THE SCIENCE OF CHANGE TO THE POLITICS OF CHANGE IN A COMPLEX WORLD

Some of the events we experience in society are small and incremental but cumulative. They slowly build up experience and wealth. That is when we are in the process of becoming progressively more efficient in economic terms. However, if we look more widely at that spinning economic process of incremental change,

we occasionally, as now, encounter the paradox that accumulated increases in wealth and efficiency also combine with an increased narrowness of view and a rigidity that make it difficult to agree on how to respond differently to new challenges. We become separate from the poor, the distant, and those who are different from us, even though they can still act independently and generate instability and surprise. Witness now the turbulence released by protest in the Middle East and the responses of the United States and Europe as they react to this turbulence and interact with each other.

Can that instability be part of a process of creative destruction? Is it part of the larger, more spasmodic cycle of transformation that can lead to a new phase of opportunity? If so, how do we act to help or even understand? How can we turn destructive events into a process of creative renewal? That process is a phase in a slower and larger part of a cycle of change that includes incremental growth in efficiency and wealth as only one, different, faster phase.

Instability creates an opportunity for a fundamental transformation of the rules that guide the relations between nations and cultures, rather than simply a change of national structure or of events. Since the Berlin Wall fell, the world has been on an internationally expanding sequence of national and international exploration, some collapses, and some hesitant, partial recoveries. Think of the collapse of the Soviet Union, of the recovery efforts in Eastern and Central Europe, of the collapse and partial economic recovery in Southeast Asia, of economic instability in Latin America, of economic, ecological, and social disaster in Africa. Of September 11.

At the moment, the world seems to be moving toward a major transformation. Part, but not all, of that transformation is the same as that seen in the inherent rhythms of natural systems summarized earlier. Complex natural systems work in rhythms, with a front-loop phase of slow, incremental growth and accumulation and a back-loop stage of rapid reorganization leading to renewal or, rarely, to collapse.

The front-loop phase is more predictable, with higher degrees of certainty. In both the natural and social worlds, it maximizes production and accumulation. We have been in that mode since World War II. The consequence of this is not only an accumulation and

concentration of wealth, but also the emergence of greater vulnerability because of the increasing number of interconnections that link that wealth, and those who control it, in efforts to sustain it. Little time and few resources are available for alternatives that explore different visions or opportunities. Emergence and novelty is inhibited. This growing connectedness leads to increasing rigidity in its goal to retain control, and the system becomes ever more tightly bound together. This reduces resilience and the capacity of the system to absorb change, thus increasing the threat of abrupt change. We can recognize the need for change but become politically stifled in our capacity to act effectively.

Should abrupt change occur, there is a move to the back-loop stage. In my opinion, this started in our international world of nations with the fall of the Berlin Wall and the collapse of communism following the earlier defeat of fascism. Both the communism and fascism of the last 70 yr fell to the slow evolution of modern democratic systems of governance. Wealth itself and broadening wealth combined to lead to our present vulnerability on a world stage. We are entering the back loop of reorganization that entails the collapse of accumulated connections and the release of bound-up knowledge and capital. However, it also opens a creative potential and the opportunity for "creative destruction" as described by Schumpeter (1942).

The creative aspect of this destruction is bound up with the release of knowledge and the appearance of new or latent elements that can then be reassociated in novel and unexpected ways to trigger regrowth or reorganization into fundamentally new front-end learning loops. That has already been occurring through the major opportunities opened up by the easy universal use of computers and telecommunication. Terrorists can use the Internet as well as "dot-coms," scientists, and citizens. This back-loop phase is inventive, inherently unpredictable, and uncertain. This process of birth, growth, and change in front-loop/back-loop cycles can be observed in all systems from a cell in the body to an individual in his or her phases of life, the operations of management agencies, and society itself.

Natural ecological and individual cycles inevitably open brief opportunities to flip to new organizations between slow periods of growth. However, social systems incorporate an additional factor. Clever

human beings have learned to look forward and create the future before it happens. These innovations are often local. Others have identified ways to persist within existing structures, avoiding the need for change; witness the brilliance of some leaders in preserving existing institutions when change and transformation are needed. However, the longer the system is “locked in,” the greater its vulnerability, and the bigger and more dramatic its collapse will be.

That has been the pattern we saw earlier when we examined resource agencies, ecosystems, and society, and the ways in which they interrelate. For resource management agencies that operate outside the discipline of a market, this results in a pathology: industries that become dependent, ecosystems that lose their resilience, and management that becomes myopic and defensive. That encourages a loss of trust in governance that can provide the crisis needed for organizational change as part of a democratic process. Examples of areas in which this loss of trust has triggered new approaches include the management of forest fires and floods and the control of lake eutrophication and pests. Typically, management becomes somewhat more complex, open, and integrative across scales of variables (Gunderson et al. 1995).

For whole societies that lack a democratic process of periodic evaluation and revision, we have seen, historically, examples of the full extreme, i.e., periods of social/economic collapse so profound that the only remaining social support for the individual was the family. This can result in a poverty trap, in which the emergence and renewal generated by deep collapses and cycles usually shift elsewhere. The novelty develops in one place and then typically move somewhere else, expanding, extending, testing, and deepening the work in each new place. The intellectual area or topic becomes the evolving entity, not the organization or society that nurtured its early phases.

The developed world has been in a phase of extraordinary wealth accumulation. The proportion of people in the world labeled as poor declined by a dramatic 50% between 1980 and 2000. Nevertheless, pockets of poverty deepen and extend in Africa. Parts of South America are on the verge of economic collapse. In all situations, both good and bad, there are implicit assumptions that the critical, hidden ecological processes that sustain economic development persist. Inevitably, this has made society

blind to the many signals of vulnerability and resistant to possible solutions. There is growing instability. Inequity between rich and poor and new physical and global impacts stemming from this inequity lead to global vulnerabilities such as global economic instabilities, climate change, biodiversity loss, unexpected diseases, and geopolitical instability. These are large in scale and consequence. They are new enough in extent that we lack the institutions to manage the transitions. They suggest a stage of vulnerability that could trigger a rare and major “pulse” of social transformation.

The world of humans has witnessed only three or four such major pulses or periods of transformation in its evolution: agricultural settlement by the first hunter-gatherers, the industrial revolution, and, now, the global interconnected communications-driven revolution. Society is now at a stage in history in which one pulse is ending and another beginning. The immense destruction that a new pulse signals is both frightening and creative. It raises fundamental questions about transformation. 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.

That leads, then, to a strategic sense of how to proceed. Do not try to plan the details, but invent, experiment, and build. Although this may sound easy, at such times existing centers of local power resist larger opportunity because of the threats they perceive in the unknown. Consequently, it is essential to do the following:

1. Encourage innovation through a rich variety of experiments and transformative approaches that probe possible directions. It is important to encourage experiments that have a low cost of failure to individuals, the environment, and careers, because many of these experiments will fail.
2. Reduce inhibitions to change, which are common when systems get so locked up.
3. Protect and communicate the accumulated knowledge and experience needed for change.
4. Promote discourse among all parties involved to try to understand where we are going and how to achieve it.
5. Encourage new foundations for renewal that build and sustain the ability of people,

economies, and nature to deal with change, and ensure that these new foundations consolidate and expand our understanding of change.

6. Allow sufficient time. This pulse is a global phenomenon, and it could potentially affect all levels of the hierarchy, all the way up the chain, from the individual/family to national and global systems.

HOW TO RESPOND IN A “BIG BACK LOOP”

The present responses of the world community at large to the possibility of transformation have been at best adequate or bad. The question is how to tip the scales more toward adequately good and achieve a better balance in the world by improving the lot of poverty-stricken populations, reducing extremes of population growth and collapse, and nurturing inventive solutions. What I observe is that the good approaches are less in ascendance at the present, and narrow, powerful, military and protectionist economic approaches are taking precedence. In the late economic bubble of the 1990s, business and government combined and dangerously usurped the balance normally provided by government. That does threaten the breadth of influence needed in a democracy. There is a tendency toward greater extremism, which ignores the broad inequities within society, or toward narrow approaches that preclude attempts to address diversity. The scale of the issues is such that they are beyond the reach of any one company, sector of the economy, or government. There is a need for a co-operative international effort that involves a major contribution to transformation by people of vision or groups of people thinking deeply about the nature of risk and finding novel ways to approach it. That is why the Internet is such a positive force at this time. It is a place for inventing the creative experiments that cover scales and that can fail safely as new possibilities are created and tested. The Internet can be inherently international.

We can act as nested sets of communities and then scale upward, trying to engage people functioning at all levels. Those are communities of citizens, really, but ones with different roots in scholarship, business, government, and nongovernmental enterprise. If Shell Oil can invent ways to open their visions of the future, and British Petroleum can begin strategic subsidy of untraditional energy supplies, surely small groups of

scholars and government and citizens can invent experiments with them outside each of their own organizational constraints. All we need is a mechanism that can encourage, evaluate, and communicate that. Our [Resilience Alliance](#) provides just such an example. It is not only local, but global as well.

People need to pay greater attention to the sustainability of the key variables of the organization in which they operate; many organizations are driven by short time frames and fast variables. Probably the greatest difficulty is to communicate the issue of time. The key feature of a sustainable, adaptive system is the need to recognize the sustaining properties of slow variables. As a system changes, it will trigger observable changes in the fast, dynamic variables, but the slower ones often will not give any observable indication of change. The people who are the most effective and active can often deal skillfully with the faster variables, but not the slower ones, because they tend to focus on short-term issues such as return on investment. It is the rare person who, for a time, defends and transcends that and organizes the turbulence for a new transformation. For me, in the past, that has been a Churchill or a Roosevelt. The resilience project describes the role of such key individuals in transformations toward ecosystem management (Westley 2002, Olsson et al. 2004).

However, both cultures and ecosystems change slowly. For example, the basic vegetation cycle in wetlands from ponds to sawgrass to fire takes a few decades to develop. In contrast, its sustainability depends on the accretion of the peat that occurs over hundreds of years, a long-term, slow variable that is not as easily recognized. In societies, the fast variables are economic ones, and the slow variables are educational and cultural. The questions are how to recognize and communicate the importance of investing in the slower variables, and how to combine the advantages of encouraging fast variables without threatening the slow ones (Carpenter 2003).

Some business leaders are already thinking about longer-term issues and cooperation, i.e., thinking outside the business envelope. There are always some companies and industries that understand that long-term change can lead to short-term scarcities, which would create new profitable markets. There is tremendous power in facilitating the growth of this understanding.

Cells and societies also reproduce and reinvent themselves in the process of cyclic transformations. That is when evolution and deep changes are created. The bewildering, entrancing, unpredictable nature of nature and people and the richness, diversity, and changeability of life come from that evolutionary dance generated by cycles of growth, collapse, reorganization, renewal, and re-establishment.

What is the role for science in the midst of this back loop of change? On substance, I'd argue for novel integrative work on ecosystem scales that focuses on economic and social as well as ecological issues. Searching for the simple features of the complex systems that occur as a result of the interactions between fast and slow and between large and small processes would also be a worthwhile endeavor, because such processes are fundamentally nonlinear in their dynamics and therefore generate occasional surprises that challenge policy and politics. This search for generality would require the cooperation of experts in other fields who share the curiosity and fun of mutual discovery. We need to develop, test, and question a range of methods and combine theory, empirical examples, and applications. That is the emphasis and the process that led to the book *Panarchy* (Gunderson and Holling 2002).

A recent paper (B. H. Walker, C. S. Holling, S. R. Carpenter, and A. S. Kinzig, *unpublished manuscript*) uses the idea of panarchy to suggest the significance of the three modes of learning and discovery. The first mode is the gradual accumulation of skills and techniques in the r to K phase (see Fig. 1). That is incremental, front-loop learning. The second mode is the mode of learning on the back loop from Ω to α . This is more profound, but still only tests the existing system, opening it to novel combinations that have accumulated from r to K . Some of those can nucleate a new cycle that is a variant, perhaps an appropriate variant, for the next cycle of change. It is very much natural selection in the Darwinian sense, but it does not transform the system. Pursuing the Darwinian metaphor, it involves some novelty in the form of crossovers and recombinations of existing options/ideas, but it does not involve real mutations. Those belong to the third mode.

The third mode of learning is transformational and does concern self-organization that can transform the system into truly novel strategies and processes. This is where transformability lies. It represents true

invention that can become reality in the kind of situation in which the system is deeply responsive (vulnerable) to change or where change is desperately needed. The consequences are inherently uncertain and unpredictable. We see those new beginnings now in the possible transformations created by the opportunities and fears opened by, e.g., the Internet, genetic engineering of crops, novel computer and communications technology. It is the transformative capacity of the world and how to nurture it that now comes most vividly to mind. It creates new panarchies.

I show my biases toward our science and scholarship by arguing for a combination of the best of multiscale synthesis, complexity theory, evolutionary biology, and human history as the foundation for understanding and managing our complex, transforming world. I also advocate a host of safe-fail experiments to test new ways of communicating, living, and sustaining our foundations.

Responses to this article can be read online at:

<http://www.ecologyandsociety.org/vol9/iss1/art11/responses/index.html>

LITERATURE CITED

- Berkes, F., J. Colding, and C. Folke.** 2004. *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge University Press, Cambridge, UK.
- Berkes, F., C. Folke, and M. Gadgil.** 1995. Traditional ecological knowledge, biodiversity, resilience and sustainability. Pages 281-299 in C. Perrings, K.-G. Mäler, C. Folke, C. S. Holling, and B.-O. Jansson, editors. *Biodiversity conservation: problems and policies*. Kluwer Academic, Dordrecht, The Netherlands.
- Brand, S.** 1999. *The clock of the long now*. Basic Books, New York, New York, USA.
- Carpenter, S. R.** 2000. Alternate states of ecosystems: evidence and its implications for environmental decisions. Pages 357-383 in M. C. Press, N. Huntley, and S. Levin, editors. *Ecology: achievement and challenge*. Blackwell, London, UK.
- Carpenter, S. R.** 2003. *Regime shifts in lake ecosystems: pattern and variation*. Excellence in Ecology Series, Volume 15. Ecology Institute, Oldendorf/Luhe, Germany.

- Elmqvist, T., C. Folke, M. Nyström, G. Peterson, J. Bengtsson, B. Walker, and J. Norberg.** 2003. Response diversity and ecosystem resilience. *Frontiers in Ecology and the Environment* 1:488-494.
- Gunderson, L. H., and C. S. Holling.** 2002. *Panarchy: understanding transformations in human and natural systems*. Island Press, Washington D.C., USA.
- Gunderson, L. H., C. S. Holling, and S. S. Light.** 1995. *Barriers and bridges to the renewal of ecosystems and institutions*. Columbia University Press, New York, New York, USA.
- Holling, C. S.** 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1-23.
- Holling, C. S.** 1978. *Adaptive environmental assessment and management*. John Wiley, London, UK.
- Holling, C. S.** 1986. The resilience of terrestrial ecosystems; local surprise and global change. Pages 292-317 in W. C. Clark and R. E. Munn, editors. *Sustainable development of the biosphere*. Cambridge University Press, Cambridge, UK.
- Holling, C. S.** 1992. Cross-scale morphology, geometry and dynamics of ecosystems. *Ecological Monographs* 62:447-502.
- Holling, C. S., and A. D. Chambers.** 1973. Resource science: the nurture of an infant. *BioScience* 23:13-20.
- Holling, C. S., F. Berkes, and C. Folke.** 1998. Science, sustainability and resource management. Pages 342-362 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Holling, C. S., L. H. Gunderson, and G. D. Peterson.** 2002. Sustainability and panarchies. Pages 63-102 in L. H. Gunderson and C. S. Holling, editors. *Panarchy: understanding transformations in human and natural systems*. Island Press, Washington D.C., USA.
- Lee, K.** 1993. *Compass and the gyroscope*. Island Press, Washington, D.C., USA.
- Levin, S. A.** 1999. *Fragile dominion: complexity and the commons*. Perseus Books, Reading, Massachusetts, USA.
- Olsson, P., C. Folke, and T. Hahn.** 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in southern Sweden. *Ecology and Society* 8(1), in press.
- Ostrom, E.** 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Cambridge, UK.
- Peterson, G., C. R. Allen, and C. S. Holling.** 1998. Ecosystem resilience, biodiversity, and scale. *Ecosystems* 1:6-18.
- Schumpeter, J. A.** 1942. *Capitalism, socialism and democracy*. Harper Books, New York, New York, USA.
- Walker, B. H., S. R. Carpenter, J. Anderies, N. Abel, G. Cumming, M. A. Janssen, L. Lebel, J. Norberg, G. Peterson, and L. Pritchard.** 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* 6(1):14. [online] URL: <http://www.consecol.org/vol6/iss1/art14>.
- Walker, B. H., and M. A. Janssen.** 2002. Rangelands, pastoralists and governments: interlinked systems of people and nature. *Philosophical Transactions of the Royal Society of London, Series B* 357:719-725.
- Walker, B. H., A. Kinzig, and J. Langridge.** 1999. Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. *Ecosystems* 2:1-20.
- Walters, C. J.** 1986. *Adaptive management of renewable resources*. Macmillan, New York, New York, USA.
- Walters, C. J.** 1997. Challenges in adaptive management of riparian and coastal systems. *Conservation Ecology* 1(2):1 [online] URL: <http://www.consecol.org/vol1/iss2/art1>.
- Westley, F.** 1995. Governing design: the management of social systems and ecological management. Pages 391-427 in L. H. Gunderson, C. S. Holling, and S. S. Light, editors. *Barriers and bridges to the renewal of ecosystems and institutions*. Columbia University Press, New York, New York, USA.
- Westley, F.** 2002. The devil in the dynamics: adaptive management on the front lines. Pages 333-360 in L. H. Gunderson and C. S. Holling, editors. *Panarchy: understanding transformations in human and natural systems*. Island Press, Washington D.C., USA.
- Whitaker, J. K.** 1987. Alfred Marshall. Pages 350-363 in J. Eatwell, M. Milgate and P. Newman, editors. *New palgrave: a dictionary of economics*. Volume 3. Macmillan, London, UK.