Resilience Thinking

Sustaining Ecosystems and People in a Changing World

Brian Walker & David Salt

Foreword by Walter V. Reid

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In the Loop:

Phases, Cycles, and Scales—Adaptive Cycles and How Systems Change

Thresholds as discussed in chapter 3 are relatively easy to appreciate because most people have experience of some aspect of an ecosystem that has gone bad and stayed that way. It might be a stinking lake that was once a popular fishing spot, or an eroded landscape that was once an agricultural breadbasket. It might be an entire swath of towns like the Rust Belt in the United States where industries are no longer competitive, or a vast area like the Aral Sea that has become a biological desert. These places have crossed a threshold into a regime in which the controls (feedbacks) are different, and it won't be easy to return to the way things were.

There is a much higher likelihood of crossing a threshold into a new regime if you are unaware of its existence. This can easily occur because resilience (which, as we discussed in chapter 3, can be defined as the distance to a threshold) is a multi-faceted measure of a social-ecological system that changes over time.

How do you identify and nurture resilience? Why do we frequently ignore it? Why do we allow something of value to degrade to a level that will impact human welfare?

This next building block of resilience thinking describes how systems move through different phases. It helps us better understand the dynamic nature of social-ecological systems and in so doing goes some way to answering these questions.

The Cycles of Life

You are born, you develop, you mature (maybe have children), and the you die. You move through different phases in the cycle of life. Families have cycles, businesses have cycles, nations and ecosystems hav cycles. They are all around us, and we exist as part of cycles occurrin over a range of scales in time and space. You might be surprised at th similarity between the various cycles at work around you.

One important aspect about cycles is recognizing that things happen in different ways according to the phase of the cycle the syste happens to be in. Sometimes things change gradually, sometimes rapidly. Sometimes surprises are more likely, sometimes innovation ha a greater chance of taking off.

By studying ecosystems all around the world, researchers have learne that most systems of nature usually proceed through recurring cycles consisting of four phases: rapid growth, conservation, release, and reorganization (Gunderson and Holling 2002). The manner in which the syste behaves is different from one phase to the next with changes in the strengt of the system's internal connections, its flexibility, and its resilience.

This cycle is known as an adaptive cycle (Gunderson and Holling 2002 as it describes how an ecosystem organizes itself and how it responds t a changing world. The notion of an adaptive cycle developed as a useful metaphor for describing change in ecological systems. However, i also has relevance for how social systems and social-ecological system change through time. And though we use the term "cycle," the reall important point is the existence of the four phases.

Although it is ecologists who have most thoroughly documented the adaptive cycle, an Austrian economist, Joseph Schumpeter, sparked the original idea. Schumpeter, who was influential in the first half of last century, analyzed the economy's boom and bust cycles, and described capitalism as a "perennial gale of creative destruction" (Schumpeter 1950) "Creative destruction" is a term now used to describe the disturbances tha periodically punctuate the adaptive cycle. It breaks down stability and predictability but releases resources for innovation and reorganization.

Four Phases of the Adaptive Cycle

Understanding the significance of a system's internal connections, its capacity to respond to disturbance, and how these aspects change from phase to phase contributes to resilience thinking. This understanding is also important for policy and for managing natural resources because it suggests there are times in the cycle when there is greater leverage to change things, and other times when effecting change is really difficult (like when things are in gridlock). The kinds of policy and management interventions appropriate in one phase don't work in others.

The Rapid Growth Phase (or r *Phase)*

Early in the cycle, the system is engaged in a period of rapid growth as species or people (as in the case of a social system such as a new business venture) exploit new opportunities and available resources. *r* is the maximum rate of growth in growth models.

These species or actors (referred to as "*r*-strategists" in ecosystems), make use of available resources to exploit every possible ecological or social niche. The system's components are weakly interconnected and its internal state is weakly regulated.

The most successful *r*-strategists are able to prosper under high environmental variation and tend to operate over short timeframes. In ecosystems they are classically the weeds and early pioneers of the world (alder on newly exposed sites in northern forests, or dock and pigweed on cleared lands). In economic systems, they are the innovators and entrepreneurs who seize upon opportunity (think of the explosive growth of Google and other dot com companies). They are start-ups and producers of new products who capture shares in newly opened markets and initiate intense activity. At higher scales we can think of the emergence and rapid growth and expansion of new societies, and even nations.

The Conservation Phase (or K *Phase)*

The transition to the conservation phase proceeds incrementally. During this phase, energy gets stored and materials slowly accumulate. Connections between the actors increase, and some of the actors change, though by the end of the growth phase few, if any, new actors are able to establish.

The competitive edge shifts from opportunists (species, people, or organizations that adapt well to external variability and uncertainty) to specialists who reduce the impact of variability through their own mutually reinforcing relationships. These "*K*-strategists" (where *K* is the parameter for "carrying capacity" or maximum population size in growth models) live longer and are more conservative and efficient in their use

of resources. They operate across larger spatial scales and over longer time periods. They are strong competitors.

In a growing business this often translates to a move toward more specialization and the greater efficiencies of large economies of scale: bigger machines, bigger outputs, smaller costs per unit, larger profits over longer timeframes (for example, a steelmaking business that grows from a local producer to a national and then a global company).

As the system's components become more strongly interconnected, its internal state becomes more strongly regulated. Prospective new entrants or new ways of doing things are excluded while capital grows (though it becomes increasingly harder to mobilize). Efficiency increases and the future seems ever more certain and determined.

In an ecosystem, the capital that accumulates is stored in resources such as biomass. Increasingly, more of it becomes bound up in unavailable forms, like the heartwood of trees and dead organic matter. An economic system's capital can take the form of built capital (machines, buildings) and human capital (managerial and marketing skills and accumulated knowledge).

The growth rate slows as connectedness increases, the system becomes more and more rigid, and resilience declines. The cost of efficiency is a loss in flexibility. Different ways of performing the same function (redundancy) are eliminated in favor of doing the function in just the most efficient way.

Increasing dependence on existing structures and processes renders the system increasingly vulnerable to disturbance. Such a system is increasingly stable—but over a decreasing range of conditions.

The Release Phase (or Omega Phase)

The transition from the conservation phase to the release phase can happen in a heartbeat. The longer the conservation phase persists the smaller the shock needed to end it. A disturbance that exceeds the system's resilience breaks apart its web of reinforcing interactions. The system comes undone. Resources that were tightly bound are now released as connections break and regulatory controls weaken. The loss of structure continues as linkages are broken, and natural, social, and economic capital leaks out the system.

In ecosystems, agents such as fires, drought, insect pests, and disease cause the release of accumulations of biomass and nutrients. In the economy, a new technology or a market shock can derail an entrenched industry. In each case, through the brief release phase, the dynamics are chaotic. But the destruction that ensues has a creative element. This is Schumpeter's "creative destruction." Tightly bound capital is released and becomes a source for reorganization and renewal.

The Reorganization Phase (or Alpha Phase)

In the chaotic release phase uncertainty rules; all options are open. It leads quickly into a phase of reorganization and renewal. Novelty can thrive. Small, chance events have the opportunity to powerfully shape the future. Invention, experimentation, and reassortment are the order of the day.

In ecosystems, pioneer species may appear from elsewhere, or from previously suppressed vegetation; buried seeds germinate; new species (including nonnative plants and animals) can invade the system. Novel combinations of species can generate new possibilities that are tested later.

In an economic or social system, new groups may appear and seize control of an organization. A handful of entrepreneurs released in an omega phase can meet and initiate a new renewal phase—turn a novel idea into a success (Nike shoes began in just this way). Skills, experience, and expertise lost by individual firms may coalesce around new opportunities. Novelty arises in the form of new inventions, creative ideas, and people.

In systems terms, the release phase is chaotic—there is no stable equilibrium, no attractor, no basin of attraction The reorganization phase begins to sort out the players and to constrain the dynamics. The end of the reorganization phase and the beginning of the new rapid growth phase is marked by the appearance of a new attractor, a new "identity."

Early in renewal, the future is up for grabs. This phase of the cycle may lead to a simple repetition of the previous cycle, or the initiation of a novel pattern of accumulation, or it may precipitate a collapse into a degraded state (in social systems, a poverty trap).

Usually, a system passes through an adaptive cycle by moving through the four phases in the order described here (i.e., rapid growth to conservation to release to renewal). But this is not necessarily so. Systems cannot go directly from a release phase back to a conservation phase, but almost all other moves can occur.

Of Budworms and Social-Ecological Systems

A good example of adaptive cycles in ecosystems comes from the spruce/fir forests that grow across large areas of North America, from Manitoba to Nova Scotia and into northern New England. Among the forests' many inhabitants is the spruce budworm, a moth whose larvae eat the new green needles on coniferous trees. Every 40 to 120 years, populations of spruce budworm explode, killing off up to 80 percent of the spruce firs.

Naturally, resource managers looking after the forest wanted to control the damage caused by the budworms. However, their first efforts were carried out without an understanding of the cycle the forest was going through.

Following World War II, a campaign to control spruce budworm became one of the first huge efforts to regulate a natural resource using pesticide spraying. The aim was to minimize the economic consequences of the pest on the forest industry. Initially, it proved a very effective strategy, but like so many efforts in natural resource management that are based on optimizing production, it soon ran into problems.

In a young forest, leaf/needle density is low, and though budworms are eating leaves and growing in numbers, their predators (birds and other insects) are easily able to find them and keep them in check. As the forest matures and leaf density increases the budworms are harder to find and the predators' search efficiency drops until it eventually passes a threshold where the budworms break free of predator control, and an outbreak occurs.

While the moderate spraying regime avoided outbreaks of budworms, it allowed the whole forest to mature until all of it was in an outbreak mode. Outbreaks over a much greater area were only held in check by constant spraying (which was both expensive and spread the problem). The early success of this approach increased the industry's dependence on the spraying program, intensified logging and spawned the growth of more pulp mills.

Now there was a critical mass of tree foliage and budworms. The whole system was primed for a catastrophic explosion in pest numbers. The managers in this system were becoming locked into using ever-increasing amounts of pesticide because the industry wouldn't be able to cope with the shock of a massive pest outbreak. The industry had little resilience, and yet the continued use of chemicals was only making the problem worse. They had created a resource-management pathology.

The industry acknowledged the looming crisis and engaged ecologists to see how they might tackle the problem from a systems perspective. In 1973, a new analysis of the dynamics of the fir forests was presented by C. S. Holling, one based on the adaptive cycle.

Forest regions exist as a patchwork of various stages of development. The cycle for any one patch begins in the rapid growth phase, when the forest is young. The patch then proceeds through to maturity as described above, and eventually, following some 40 to 120 years of stable and predictable growth, the cycle tips into the release phase. The larvae outstrip the ability of the birds to control them, larvae numbers explode, and the majority of forest trees are killed. Their rapid demise opens up new opportunities for plants to grow, and during the reorganization phase the forest ecosystem begins to reestablish itself. The cycle then repeats.

With this understanding of the cycle and the key changing variables that drive the system, the forest managers were able to fundamentally modify the manner of their pest control. Rather than continually using low doses of pesticide over wide areas they switched to larger doses applied less frequently at strategic times over smaller areas. They reestablished a patchy pattern of forest areas in various stages of growth and development rather than keeping wide areas of forest primed for a pest outbreak.

The forest industry also changed through the process, moving to regional leadership with a greater awareness of the ecological cycles that underpinned the forest's productivity.

From Budworms to Resilience Thinking

The example of the spruce budworm and the fir forest is important on many levels as it was in part the genesis of what has become resilience thinking. During his investigations, C. S. "Buzz" Holling proposed that the key to sustainability was an ecosystem's capacity to recover after a disturbance. He also recognized that the ecosystem and the social system needed to be viewed together rather than analyzed independently, and that both went through cycles of adaptation to their changing environments. Adaptive cycles don't just happen in nature, they happen in communities, businesses, and nations.

His proposal catalyzed the thinking of ecologists and researchers (with an interest in systems) all over the world because similar patterns were being identified everywhere social-ecological systems were being studied. Over the decades since then the models and the thinking

associated with managing for resilience have gone through much refinement but the two core areas remain at its heart: the fact that social-ecological systems can exist in different stable states and that they constantly move through adaptive cycles over many linked scales (which we discuss later in this chapter).

Fore Loops and Back Loops

Taken as a whole, the adaptive cycle has two opposing modes. A development loop (or "fore" loop), and a release and reorganization loop (or "back" loop) (see figures 9 and 10). The fore loop (sometimes called the front loop or forward loop) is characterized by the accumulation of capital, by stability and conservation, a mode that is essential for system (and therefore human) well-being to increase. The back loop is characterized

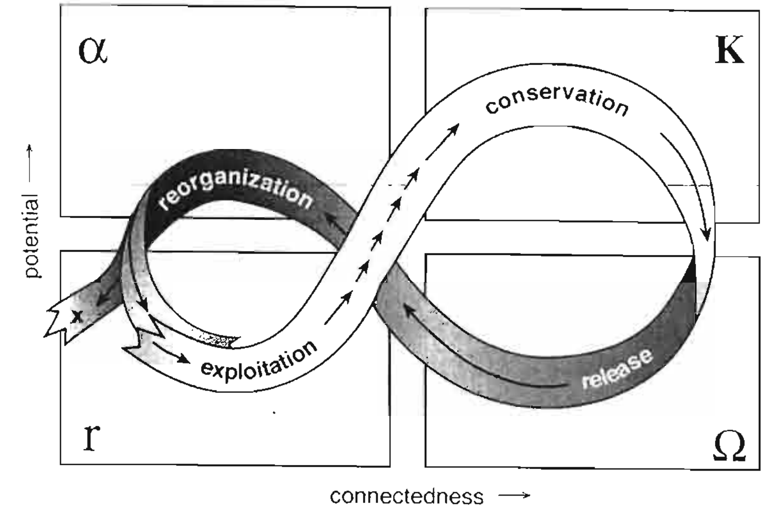

FIGURE 9 The First Version of the Adaptive Cycle

The first versions of the adaptive cycle pictured it as a figure 8 in two dimensions with the axes being connectedness and potential. Potential reflects accumulated growth and storage (biomass that is increasingly inactive like heartwood in trees or leaf litter). The use of the simpler loop, as shown in figure 10, has been adopted because it better reflects the passage from release to reorganization in some systems. However, because the adaptive cycle in the shape of the number 8 (as shown here in figure 9) was the original version it has iconic value, and it is often seen as a symbol of studies on resilience and adaptive cycles. *(From Gunderson and Holling, 2002.)*

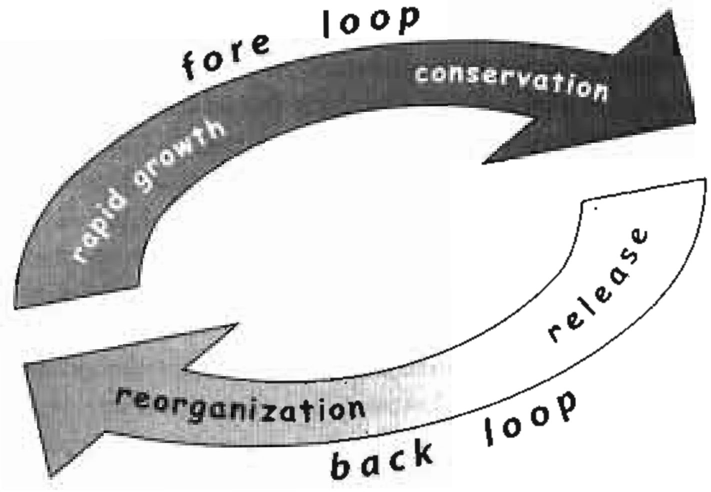

FIGURE 10 A Simple Representation of the Adaptive Cycle

The rapid growth and conservation phases are referred to as the fore loop with relatively predictable dynamics and in which there is a slow accumulation of capital and potential through stability and conservation. The release and reorganization phases are referred to as the back loop, characterized by uncertainty, novelty, and experimentation and during which there is a loss (leakage) of all forms of capital. The back loop is the time of greatest potential for the initiation of either destructive or creative change in the system

by uncertainty, novelty, and experimentation. The back loop is the time of greatest potential for the initiation of either destructive or creative change in the system. It is the time when human actions—intentional and thoughtful, or spontaneous and reckless—can have the biggest impact.

It is important to reemphasize that the adaptive cycle is not an absolute; it is not a fixed cycle, and many variations exist in human and natural systems (see figure 11). A rapid growth phase usually proceeds into a conservation phase but it can also go directly into a release phase. A conservation phase usually moves at some point into a release phase but it can (through small perturbations) move back toward a growth phase. Clever managers (of ecosystems or of organizations) often engineer this in order to prevent a large collapse in the late conservation phase. That is, they avoid a release phase at the scale of concern (the whole forest or the organization) by generating release and reorganization phases at lower scales thereby preventing the development of a late *K* phase at the scale of concern.

Cycles of Nature and People

The easiest way to appreciate adaptive cycles is to observe them. Think of a forest, going through a succession from pioneer to climax species. This is the front loop that sees the forest resources slowly being accumulated and locked up in the trees and the various organisms they support. It's a long reasonably predictable phase of increasing growth. The longer it persists the more efficient it becomes in using the resources, and in so doing it eventually locks those resources up. As this occurs, the forest becomes less resilient, and more vulnerable to shocks and disturbances. At some point, inevitably, the forest will experience a disturbance such as a fire, storm, or pest outbreak big enough to precipitate a collapse, releasing accumulated nutrients and biomass. The longer the forest has been in the late conservation phase, the smaller is the size of the disturbance needed to send it into release. By comparison to the fore loop, the back loop is brief. The forest reorganizes, and sets up the start of a new cycle.

But think also of human systems. Consider a new business that builds houses. Being new, the business is trying out new and innovative ways of doing things, and is keen to build up its market. It proves successful and starts growing. Over time it starts adapting to its own

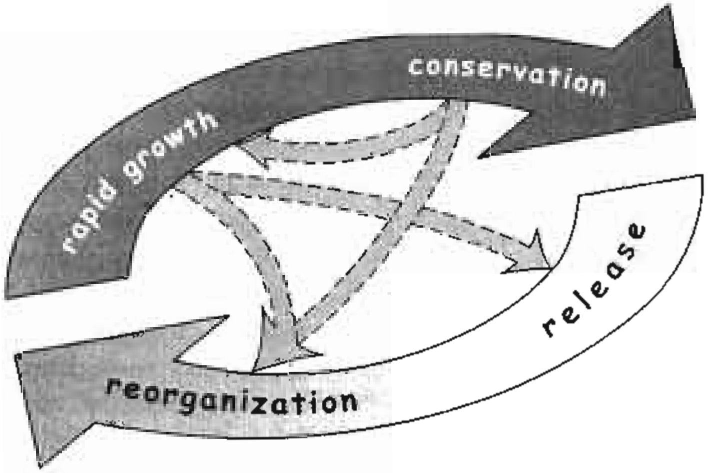

FIGURE 11 Variants of the Adaptive Cycle

Transitions are possible (and have been observed) between all phases except from the release or reorganization phases directly to the conservation phase success by being more efficient at doing the things that it does well. Resources are locked up in doing things in the most efficient manner such as in buying equipment for building houses in one set manner or tailoring the product to specifically meet the needs of just one subset of the market.

In so doing, however, the business is becoming less resilient as it concentrates on doing things in one or only a few different ways. If it invests in doing a wide variety of things, or in doing each thing in several different ways, it's being less efficient than focusing on just the things it does especially well. However, this loss of flexibility means it's more vulnerable to shocks and disturbances, such as an economic recession in which people cut back dramatically on house building or the appearance of a competitor who provides different kinds of houses. The business is totally dependent on houses being built in a particular way so it goes broke. It has entered the back loop. The resources it had locked up (people and capital) are now released and made available to the remnants of the company and new innovators that will be the trendsetters of the next cycle. The original company may or may not be a part of it.

Consider the global energy market and how it is dominated by fossil fuels. For many years scientists and economists everywhere have been talking about the need to move to alternate and renewable forms of energy production and yet we seem locked into our dependence on fossil fuel. For many it seems irrational, but it's in keeping with the adaptive cycle in which the front loop has experienced a slow, predictable pattern of growth in the fossil fuel industry in which resources are locked up into doing things in the most efficient way. But, in so doing, it has lost the capacity to do things in different ways. Too many institutions and businesses are now dependent on maintaining the status quo of fossil fuel usage. Innovation for alternatives is either quashed or receives inadequate support. A consequence of this is that it lacks resilience. Fossil fuels have a limited life span and at some point a shock will lead to a collapse, a major disruption of the industry. Whether or not this is a sudden, costly, painful change will depend on whether the industry has the ability to transform itself ahead of time.

If it's a sudden collapse, in the back loop that follows, the resources it has locked up will be released toward innovation in different areas. The later this happens, the bigger will be the losses in the release phase. And the next forward loop of the cycle will be different from that which would take place if the reorganization were to occur earlier. We can't say exactly how it will be different, but if the collapse phase is bigger it's likely that at least the start of the next loop will witness a period of reduced human well-being.

There is, of course, the option to choose a transition to an energy mix that is sustainable (as is being attempted in some European countries). Such actions and induced changes constitute either a reverse move, from late conservation back to early conservation phase through small-scale changes, or a direct move at the scale of the whole industry through a rapid renewal phase to a new front loop, attempting to minimize the costs of the release phase.

Because the back loop is a time of uncertainty and big change, in which the usual order undergoes significant and unpredictable rearrangement, it is feared and held off by those in power. However, no system can stay in, or be kept in, a late conservation phase indefinitely. Unless there is a deliberate effort to simplify the complexity, to release some of the potential and slide back toward the rapid growth phase, or (as is suggested) engineer a very rapid, minimal cost conservation-to-reorganization transition, a significant back loop of one form or another is inevitable.

Dangers of the Late *K* Phase

We stress that the fore loop is crucial for capital accumulation (all forms of capital). It is where levels of human well-being can be raised. Capital does not accumulate during periods of release and renewal. From rapid growth to mid-conservation is a period of accumulating capital but also a time of high to moderate resilience.

However, things are not so positive as you move into the late *K* (conservation) phase where the system begins to become locked up. This situation is characterized by:

- Increases in efficiency being achieved through the removal of apparent redundancies (one-size-fits-all solutions are increasingly the order of the day);
- Subsidies being introduced are almost always to help people *not* to change (rather than *to* change);
- More "sunk costs" effects in which we put more of our effort into

BOX 6 Of Levees, Cycles, and Windows

The adaptive cycle explains why sometimes a good idea by itself isn't enough to cause something to happen; it needs a window of opportunity to really work. While it may take off during the reorganization phase, if left till the *K* phase you've probably missed your opportunity.

Take, for example, an innovative proposal in the lower Goulburn-Broken Catchment to dismantle a series of flood control levees to reestablish the natural function of a floodplain adjoining the Goulburn River. The flood levees were established around 100 years ago following a series of damaging floods. As with most of the examples of command and control presented in this book, the flood levees solved one short-term problem but created a series of larger scale issues. In this case, small and medium floods were kept off the extensive River Red Gum flood plains to the north. This protected the crops being grown there but removed the regular flooding that sustained the River Red Gum ecosystems. Instead of allowing the floodwaters to cover the flood plains, the floodwaters were forced down the main channel causing extensive erosion and environmental damage to the river channel.

While the levees contained small-to-medium floods, larger floods (which occurred most decades) were not contained. Not only did they breach the levees on the northern side, pouring out over the flood plain, they also breached the levees on the southern side, allowing floodwaters to damage valuable irrigation land.

It was very much a lose-lose situation. The levees cost a lot to maintain, harmed a valuable ecosystem, failed about once every 10 years, and exacerbated the damage caused by moderate floods. Their only value was to protect low-value cropping land from small floods. It is interesting to note how we can stick with bad ideas over long periods because innovation is so challenging to introduce.

The spring floods of 1993 were particularly bad causing AUS$1 million damage to the levees and AUS$20 million in losses and damage to adjoining infrastructure and agricultural production.

The scale of damage finally galvanized action. The Catchment Management Authority proposed to dismantle the levees on the northern side of the river. This would allow floodwaters to once again pour over some of the original floodplain. The River Red Gum floodplain would be rejuvenated, the main river channel would not be scoured in times of flood and the valuable agricultural lands to the south of the river would be significantly better protected.

The main cost of the scheme would be the purchase of 10,000 hectares of privately owned land on the floodplain by the government, the cost of which would be less than the damage bill of the single event in 1993.

Unfortunately, the proposal, which was touted by most parties as an environmental triumph with economic benefits, took several years to work up and was met with resistance from a few people with a vested interest in keeping parts of the floodplain in private ownership. More studies were called for to clarify minor aspects of the proposal and the process dragged on. The further away from the catalyzing floods of 1993, the fewer people seemed to care whether or not it got up.

In 2005, following the worst drought on record, the window of opportunity appears to have closed on this particular proposal, at least until the next flooding event, when this region may enter another phase of creative destruction (in its passage through the adaptive cycle). Then, with the proposal all ready, it may have its window to fly.

And, if you think about it, natural flooding in this system really is creative in its destruction. It destroys weeds; moves debris around, deposits silt and nutrients; triggers breeding by fish, amphibians, and water birds; and replenishes billabongs (bodies of water like small oxbow lakes), wetlands, and streams. The levee system was an attempt to control creative destruction. Unfortunately, it got rid of the creative and simply left the destruction.

continuing with existing investments rather than exploring new ones (the Concorde effect);
- Increased command and control (less and less flexibility);
- A preoccupation with process (more and more rules, more time and effort devoted to sticking to procedures);
- Novelty being suppressed, with less support for experimentation; and
- Rising transaction costs in getting things done.

Capital doesn't accrue in the late *K* phase either, and the likelihood of a major collapse is high. So, if the system is in late *K*, the first question is how to undo some of the constraints. Any release phase is costly and unpleasant and involves loss of capital (social, economic, and natural), so if a release seems inevitable, then the question becomes: How can we navigate a graceful passage through the back loop?

While a system may stay in a late conservation phase for some time, it can't stay there forever; complex systems don't work that way. The costs involved in staying in this late conservation phase increase over time. At the scale of a society or a nation, when those costs exceed the benefits of all the fix-up solutions, the society collapses (Tainter 1988).

A Window of Opportunity

As should be evident by now, a back loop is not all bad. It is a time of renewal and rejuvenation, a period of new beginnings and new possibilities—hence its description as a period of creative destruction.

Droughts and floods can trigger creative destruction but so too can economic recessions, wars, and the deaths of powerful leaders (consider the discussion on adopting new ways for thinking and paradigm shifts in chapter 2). These events may be traumatic and destroy property and people but they also make it possible for new beginnings. And those new beginnings can often grow to be ruling paradigms in the next front loop. They are critical times to achieve change and reform in a constantly moving social-ecological system.

Think back to the Everglades. Its history has been characterized by cycles of disturbance, release, reorganization, and incremental growth. It is currently in a state of legislative gridlock in which it may take a new disturbance to move things along.

Once you move out of the back loop, opportunities for innovation and novelty shrink and eventually shut down as the slow grind of the front loop starts to squeeze out new entrants, new ideas, and different ways of doing things.

The Importance of Scale(s)

When we talk about adaptive cycles in social-ecological systems it is easy to become too focused on the specific scale in which we're interested. If we're talking about a farm or a business, we usually think only of that farm or that business. But the scale in which we are interested is connected to and affected by what's happening at the scales above and below, both in time and space. At each scale the system is progressing through its own adaptive cycle, and the linkages across scales play a major role in determining how the system at another (linked) scale is behaving. We've already described how generating disturbances at lower scales can keep a system at a higher scale from progressing to a late *K* phase.

What all this means is that any system you can imagine is actually composed of a hierarchy of linked adaptive cycles operating at different scales (both in time and space). The structure and dynamics of the system at each scale is driven by a small set of key processes and, in turn, it is this linked set of hierarchies that govern the behavior of the whole system. This linked set of hierarchies is referred to as a "panarchy."

The term "panarchy" was originally coined by Buzz Holling and Lance Gunderson to describe the cross-scale and dynamic character of interactions between human and natural systems. It draws on the Greek god Pan, a symbol of universal nature, to capture an image of unpredictable change, and fuses this with notions of hierarchies—cross-scale structures in natural and human systems. The term embodies notions that sustain the self-structuring capacity of systems (system integrity), allow adaptive evolution, and at times succumb to the gales of change.

It's important to get this multi-scale structure and dynamics clearly in mind, and it helps to consider a couple of examples. Think again about the conifer forests in North America. The finest scale (for our purposes) is the leaf, or individual conifer needle. The next scale up is the crown of the tree. Figure 12 shows the full range of space and time scales, for both the forest and for the processes that produce this structure.

Structure at the leaf scale, measured in centimeters, is driven by plant physiology and environmental conditions operating over time scales up to

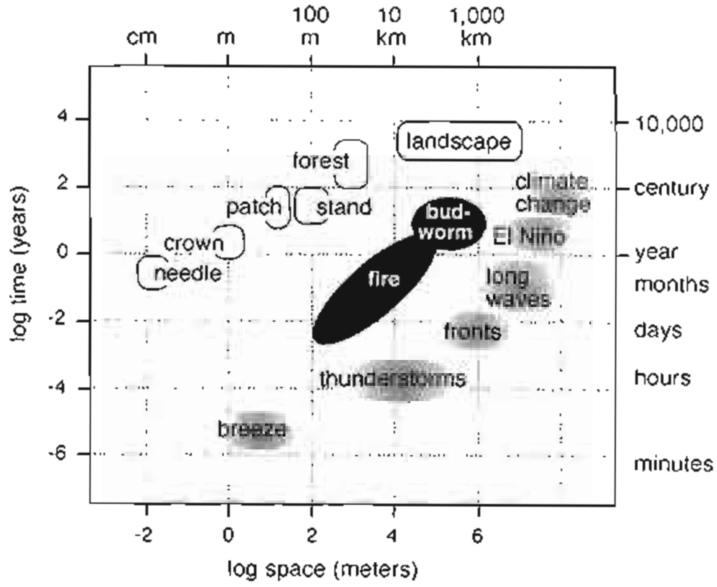

FIGURE 12 Time and Space Scales of the Boreal Forest
(From Gunderson and Holling, 2002.)

a year—the generation time of a needle. Canopies operate in scales of meters and cycle with a generation time of around ten years. Trees cycle with a generation time of a hundred years or more. At the forest patch structure the relative numbers and sizes of different tree species—working on scales of tens of meters—is driven by competition for light, water, and nutrients, and cycles over centuries. The structure of the whole forest operates at distance scales of kilometers, timescales of centuries. It is driven by processes such as fires, storms, and insect outbreaks. At the level of the landscape, and at scales of thousands of kilometers, climate, geomorphologic, and biological processes drive changes at time scales from centuries to millennia.

Interacting with the natural system scales is a set of social scales of human activities using and working in and around the forest. There are time and space scales relating to individual workers, their families, and their communities. There are also time and space scales relating to the operation of the forestry business, the equipment it uses, the industry it's a part of, and the overall demand for wood products that relate to bigger cycles of economic prosperity and growth. The cross-scale dynamics of the natural and social components of this complex system constitute the panarchy that is an interlinked system of people and nature.

Very importantly, the processes that produce these panarchy patterns are in turn reinforced by those patterns—that is, *the patterns and processes are self-organizing*. This is a key aspect of complex adaptive systems (see chapter 2).

Connecting Across Scales

Of particular interest are linkages across scales. They are a key aspect of the multiscale adaptive cycles that make up a panarchy. What happens at one scale can influence or even drive what's happening at other scales.

Ignoring the effects of one scale on another (cross-scale effects) is one of the most common reasons for failures in natural resource management systems—particularly those aimed at optimizing production. The lesson is that you cannot understand or successfully manage a system—any system, but especially a social-ecological system—by focusing on only one scale. So often people concentrate solely on the scale of direct interest to them (their farm, their company, their catchment, or their country), but the structure and the dynamics at that scale, and how the system can and will respond at that scale, strongly depends on the states and dynamics of the system at the scales above and below.

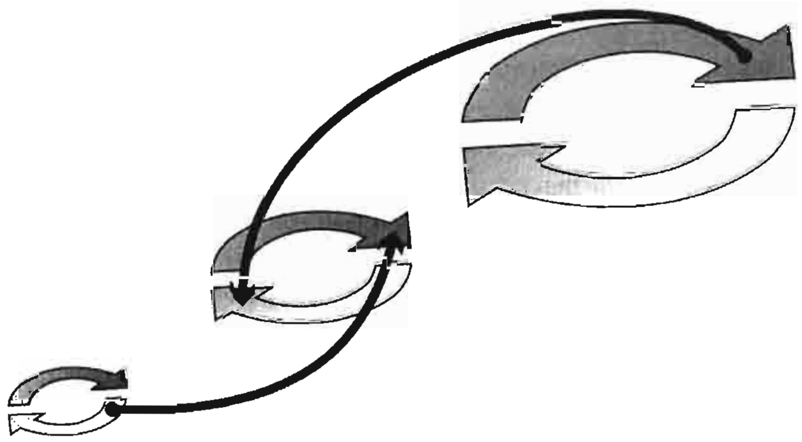

FIGURE 13 Panarchy Refers to Hierarchies of Linked Adaptive Cycles

Some obvious examples: individual farmers who wish to clear trees from their lands, or drain excess irrigation water into rivers, may be constrained by higher level regulations. Their ability to sell their produce may be affected by changes in preferences at the scale of the market. And, in times of severe hardship (a drought) the help they may or may not get from the scale of organization above (often some level of government), depends on the state the system happens to be in, at that scale, at that time. For example, if a nation's economy is strong going into a drought there might be strong community demand for the government to provide drought assistance to farmers. However, if a nation is in economic depression then drought assistance is unlikely.

The recovery path of a forest patch that has been devastated by a fire or cyclone depends on the availability of seeds of the many species in the surrounding mature forest. That is, it depends on the "memory" of the system at the scale of the whole forest. The recovery pattern of communities of people that have been subject to a devastating shock (environmental, economic, or social) will depend on the memory of how to respond, embedded at the higher scale of the society in which the community exists.

Bottom-up linkages can be equally important. At the scale of a forest the individual patches, going through their own (faster) cycles, may produce a kaleidoscopic effect in which the forest, as a whole, may appear to remain much the same if considered as an average of the patches. But if many of the patches get into the same phase of their cycle (too much synchronization) a change in one can trigger others and the effect can cascade upward to a change in the whole forest. This is what happened when pesticides were used to control the spruce budworm. The pesticide use prevented forest patches from succumbing to pest outbreaks but synchronized wider areas of the forest patches.

Continuing the fossil fuel example, if the fossil fuel industry were to collapse it would likely drive many economies into recession or depression. This economic downturn might tip many businesses, which operate on smaller scales (and which were not thinking about the fossil fuel industry scale), into their own back loops.

Sometimes the connection with larger scales can perpetuate a conservation (*K*) phase at smaller scales that might otherwise have ended. In the Everglades, the continued drive to develop, drain, and regulate the waters of the marshlands may have been abandoned if there hadn't been massive injections of resources from the federal government. Subsidies from a higher scale frequently prolong a *K* phase that would otherwise have moved into a back loop.

In the Goulburn-Broken Catchment (GBC), one of the important factors that allowed the region to create new levels of organization to address the crisis of the underground flood of the 1970s was the higher scales of state and federal government relaxing their control and allowing for the devolution of authority to local authorities. The success of the Goulburn-Broken Catchment Management Authority in addressing aspects of the groundwater problem served as an example to other regions and states that then established their own catchment management authorities. An innovation in one catchment propagated up to influence the larger scale.

But there's another interesting cross-scale effect in the case study on the GBC. In the 1970s, just as high rainfall caused an enormous rise in groundwater killing many of the region's fruit trees, England had just joined the European Union and Australia lost an important export market for its fruit. The price being paid for fruit from the GBC plummeted, and this served to mask the impact of the rising groundwater because now the produce from the dying trees wasn't worth much. Farmers were pulling out trees anyway. Had there not been this market impact it's believed a lot more would have been done at that time to address the problem of the rising groundwater. Another possibility may have been that the fruit industry in the GBC would have moved to another area.

Thresholds and Adaptive Cycles

Thresholds (chapter 3) and the adaptive cycle metaphor are both central to resilience thinking. Adaptive cycles describe how many systems behave over time, and how resilience varies according to the phase where the system lies. Thresholds represent transitions between alternate regimes. While the two concepts can sometimes be related in the pattern of a particular system's dynamics, this not always the case. They are different models used for different purposes, and it is not always possible to equate the dynamics of a basin of attraction with the dynamics of an adaptive cycle. Where they do coincide, however, alternate regimes generally represent a new adaptive cycle, indicating that the system has new structures and feedbacks.

When a social-ecological system crosses a threshold into an alternate basin of attraction (say a catchment becomes salinized or a coral reef stops regenerating) it often occurs during a back loop. Linkages that bound the system in the conservation (*K*) phase are broken during the release phase. Some species may fail to recolonize during the subsequent reorganization phase with the result that a loss of species occurs, possibly also a collapse in productivity. These changes may represent a new system regime, and a new adaptive cycle.

However, crossing a threshold may occur in situations where the adaptive cycle phase of disturbance is small relative to larger environmental changes. A patch of rangeland, for example, that shifts from a grassy regime to a shrubby regime doesn't mark a collapse in the system, at that scale. There is no unraveling or chaotic dynamics. If enough patches flip, however, it can trigger a collapse of the farm as an enterprise.

One example that illustrates how resilience, thresholds, and adaptive cycles are related is the successional changes that occur in the transitions from a beaver pond to a bog to a forest. Each of the stages in this well-known development sequence is distinctive in the way it looks and functions. Each marks a transformative change from the preceding system. The changes are transformative because in each case the system has a new way of functioning and new identifying variables come in to the system—bog plants in the first transformation, trees in the second. These are not alternate regimes in the same system; they are different systems. But each transformation occurs without a release phase—there is no catastrophic loss of nutrients, for example. This is an example of adaptive cycles involving progression from a rapid growth phase to a conservation phase and then briefly through a reorganization phase (as the new species enter) and then to a newly self-structuring growth phase of bog or (in the next round) forest. This type of development may be characterized as a series of steps, with each system a different step.

Each transition is a consequence of a loss of resilience in the existing system. Starting with the pond, as it gets shallower its ability to resist the invasion of bog plants gets smaller. Eventually it is overwhelmed during some small shift in pond depth (a small drought or seasonal effect) and the bog gets established. The bog grows vigorously until it reaches an advanced stage with lowering water levels and with reduced vigor and self-organizing ability. If, before this time, a fire should occur the likely consequence is a short back loop of release and reorganization, and a new invigorated bog growth phase. As sediments increase, however, and bog conditions diminish, trees gradually establish in the bog, first on hummocks, until a drought or some other disturbance gives the trees the upper hand throughout. The more developed the bog, the smaller the shock until tree invasion inevitably occurs—with no release—and reorganization into a forest system follows. Each transition is a consequence of a loss of resilience due to a slowly changing variable (water depth/saturated soil depth) with a threshold where feedbacks change and a regime shift (in this case a transformational one) takes place.

Complex Science and Back Loops

We've pointed out that the fore loop is generally slow compared to the back loop. In fact, most systems spend by far the majority of their time in a fore loop. So if you look around, by far the majority of what you see will be systems in fore loop phases.

It is therefore not surprising that nearly all our research, and all our management and policy development, has been done in and created for fore loop behavior. Almost none has been done in systems in their brief but critically important back loop periods.

Recognition of the enormous importance of the back loop is very recent. It is part and parcel of appreciating that we live a complex world. It is a major component of resilience thinking and an important point of difference with traditional science that has modeled the world based on the assumption that change is incremental and predictable. Yes, change is incremental and predictable in the fore loop but to limit our management and policy to the parts of the world that we understand while ignoring those parts that are difficult is to set ourselves up for failure.

Key Points on Resilience Thinking

- Social-ecological systems are always changing and many changes reflect a progression through linked adaptive cycles, on different scales of time and space, with each cycle consisting of four phases: rapid growth (*r*), conservation (*K*), release (omega) and reorganization (alpha).
- Most of the time, social-ecological systems are changing along the growth to conservation phases (fore loop) of the cycle in which growth and development are incremental, life is fairly predictable, and resources get locked up in doing things in an increasingly efficient manner. Optimization for immediate benefits can work in these phases (for a while).
- Inevitably, the conservation phase will end. The longer the conservation phase persists, the smaller the shock needed to end it and initiate a release phase in which linkages are broken and natural, social, and economic capital leaks out of the system. The system then reorganizes itself. In this back loop passage through release and reorganization, uncertainty and instability are high and optimization does not work.
- While the cycle just described is the most common pattern of system dynamics, other transitions between the four phases can, and do, occur.
- Linkages across scales are very important for how the system as a whole operates.
- By understanding adaptive cycles you gain insight into how and why a system changes; develop a capacity to manage for a system's resilience; and, most importantly, learn where and when various kinds of management interventions will, and will not, work.