Chapter 1.
In Search of a Theory of Adaptive Change

In all things, the supreme excellence is simplicity
-Henry Wadsworth Longfellow

C. S. Holling
L.H. Gunderson
D. Ludwig

Introduction

In the last decade of the 20th century, or since the Berlin wall fell, cascades of changes have occurred on the global scale. These include collapse of the former Soviet Union, and its subsequent decade-long struggle for stability, the collapse of the Asian financial market and its contagious effects on world markets, increases in connectivity through the Internet, and increased migration of people (forced and not). There have been dramatic changes in global ecological systems -- from climate change that is already upon us, to the ozone hole and the emergence and propagation of novel diseases. The tragedy of AIDS, its origins, transformation and dispersion because of land use and social changes, is a signal of deep and broad changes that will yield further surprises and crises. More and more evidence accumulates that global climate change has already produced an increase in severe weather that, combined with inappropriate coastal development, has caused dramatic rises in insurance claims and human loss of life. Still other more subtle changes linking ecological, economic and social forces are occurring on a global scale such as the typical example described in Box 1-1, regarding collapse of fisheries.

We see similar patterns of change at a regional scale, as well. These include dramatic changes in the ecosystems and landscapes of ecosystems, with subsequent changes for society and economic conditions. There are spasms of biodiversity loss as a consequence of the intersection of climate extremes, poor land use and global economic pressures. In places, such as in some nations in southeast Africa, these exacerbate political instability. The results are not only erosion of the natural world but also erosion of trust in the institutions of governance.

How do we begin to track down the cause of these failures in sustainability? Consider some more examples:

- Why do fisheries collapse in spite of widespread public support for sustaining them and the existence of a highly developed theory of fisheries management?
- Why does moderate stocking of cattle in semi-arid rangelands increase vulnerability to drought?
- Why does pest control create pest outbreaks that become chronic?
- Why do flood control and irrigation developments create large ecological and economic costs and increasing vulnerability?

A number of case examples point to a common cause behind the failure of management of renewable resources (Holling 1986, Gunderson et al. 1995). In each case, a target variable (fish stock, meat production, pest control, and water levels) is identified and successfully controlled. Uncertainty in nature is presumed to be replaced by certainty of human control. Social systems initially flourish from this ecological stabilization and resulting economic opportunity. But that success creates its own failure.

Box 1-1. Fishing down the food web

D. Ludwig

Although total catch levels for marine fisheries have been relatively stable in recent decades, analysis of the data shows that landings from global fisheries have shifted from large piscivorous fishes toward smaller invertebrates and planktivores (Pauly et al. 1998). This shift can be quantified through assignment of a fractional trophic level to each species depending upon the composition of the diet. The values of these trophic levels range from a value of 1 for primary producers to over 4.6 for a few top predators such as a tuna in open water and groupers and snappers among bottom fishes. For data aggregated over all marine areas, the trend over the past 45 years has been a decline of the mean trophic level from over 3.3 to less than 3.1. In the Northwest Atlantic, the mean trophic level is now below 2.9. There is not much room for further decreases, since most fish have trophic levels between 3 and 4. Indeed, many fisheries now rely on invertebrates, which tend to have low trophic levels.

Global trends appear to show a decline of 0.1 trophic level per decade. This is an underestimate of the actual change, since data from many areas, especially in the tropical developing countries, are lumped into categories such as "mixed fishes" that do not reflect changes in trophic level. Moreover, the analyses performed so far did not consider the decline in trophic level that occurs within species due to the increased removal of older fishes, which tend to have higher trophic levels than the young of the same species. It is likely that a continuation of present trends will lead to widespread fisheries collapses. These trends cast doubt on the idea of estimating future catches by extrapolation of present trends.

The costs of this devastation are difficult to observe since the massive exploitation of stocks is often associated with a displacement of small--scale traditional fisheries by large industrial ones. The small fishers are then jobless and they move to cities. The costs of this conversion of members of society from being productive to being unproductive are borne by the society as a whole, and are not ascribed to their displacement from the fishery.

Paradox 1: The Pathology of Regional Resource and Ecosystem Management:

Observation: New policies and development usually succeed initially, but they lead to agencies that gradually become rigid and myopic, economic sectors that become slavishly dependent, ecosystems that are more fragile and a public that loses trust in governance.

The Paradox: If that is as common as it appears, why are we still here? Why has there not been a profound collapse of exploited renewable resources and the ecological services upon which human survival and development depends?

We now know that the stabilization of target variables, like these, leads to slow changes in other ecological, social and cultural components -- changes that can ultimately lead to the collapse of the entire system. A pattern of events emerges: at the extreme, the ecological system fails, the economic system reconfigures and the social structures collapse or move on. Moderate, stabilized grazing by cattle reduces the diversity of the rangeland grasses, which eventually leads to fewer drought-resistant species, less permeable soils and poor water retention. Pest control leads to more luxuriant growth of the host plants, and hence creates more favorable conditions for survival and reproduction of the pest. Effective flood control leads to higher human settlement densities in the fertile valleys, and a large investment in vulnerable infrastructure. When a large flood eventually overwhelms the dams and dikes, the result is often a dramatic reconfiguration of the social and economic landscape along the river. And, as described in Box 1-1, the initial success of fisheries leads to an increase in investment and overexploitation of the resource. When the fish stock shows signs of distress, management agencies become paralyzed, the public loses trust in governance, and human institutions are unable to make the required adjustments.

It should be mentioned that many of these problems can be analyzed from an economic standpoint. According to this view, resources are appropriated by powerful minorities who are able to influence public policy. Hence inappropriate measures such as perverse subsidies are implemented that deplete resources and create inefficiencies (Magee, Brock and Young 1989). Hence a fundamental cause of the failures is the political inability to deal with the needs and greed of people, and rent-seeking by powerful minorities. But there are, as well, contributing causes that provide the ammunition for political manipulation. This book concentrates on those. Some of this ammunition comes from the very disciplines that should provide deeper and more integrative understanding, primarily economics, ecology and institutional analysis. That leads to the second paradox : The Trap of the Expert. So much of our expertise loses the sense of the whole in the effort to understand the parts.

Paradox 2: The Trap of the Expert

<u>Observation:</u> In every example of crisis and regional development we have studied, both the natural system and the economic components can be explained by a small set of variables and critical processes. The great complexity, diversity and opportunity in complex regional systems emerge from a handful of critical variables and processes that operate over distinctly different scales in space and time.

<u>The Paradox:</u> If that is the case, why does expert advice so often create crisis and contribute to political gridlock? Why, in many places, does science have a "bad name"?

We begin unraveling this paradox, with an examination of the obstacles that arise from not just from multiple, scientific perspectives but also from disciplinary hubris. The complex issues connected with the notion of sustainable development are not just ecological problems, nor economic or nor social . They are a combination of all three. Actions to integrate all three typically short-change one or more. Sustainable designs driven by conservation interests can ignore the needs for a kind of economic development that emphasize synergy, human ingenuity, enterprise and flexibility. Those driven by economic and industrial interests can act as if the uncertainty of nature can be replaced with human engineering and management controls, or ignored altogether. Those driven by social interests often presume that nature or a larger world presents no limits to the imagination and initiative of local groups.

Compromises among those viewpoints are arrived at through the political process. However, mediation among stakeholders is irrelevant if based on ignorance of the integrated character of nature and people. The results may be satisfying to the participants, but ultimately reveal themselves as based upon unrealistic expectations about the behavior of natural systems. As investments fail, the policies of government, private foundations, international agencies and non-governmental organizations flop from emphasizing one kind of partial solution to another. Over the last three decades, such policies have flopped from large investment schemes, to narrow conservation ones to, at present, equally narrow community development ones.

Each approach is built upon a particular world-view or theoretical abstraction, though many would deny anything but the most pragmatic and non-theoretical foundations. The conservationists depend on concepts rooted in ecology and evolution, the developers on variants of free market models, the community activists on precepts of community and social organization. All these views are correct. Correct in the sense of being partially tested and credible representations of one part of reality.

The problem is that they are partial. They are too simple and lack an integrative framework that bridges disciplines and scales.

Partial Truths and Bad Decisions

The fields of economics, ecology, organizational or institutional analysis have developed tested insights. Yet, there is growing evidence that the partial perspectives from these disciplines generate actions that are unsustainable. One way to generate more robust foundations for sustainable decision making is to search for integrative theories that combine disciplinary strengths while filling disciplinary gaps. . But before we can begin such a task, we should examine the partial constructs that characterize these fields.

Economics

Modern neoclassical economics has gone far in discovering the process whereby millions of decisions made by individuals give rise to emergent features of communities and societies (e.g. rate of inflation, productivity gains, level of national income, prices, stocks of various types of capital, cultural values and social norms). Two factors make economic theory particularly difficult: First, individual decisions at any moment are themselves influenced by these emergent features and by past decisions. Learning, practice, and habit influences the moment as much as present prices do. Second, the emergent features that can be well handled by standard neoclassical economic theory and policy concern only fast-moving variables that define present conditions. The more slowly emergent properties that affect attitudes, culture and institutional arrangements are recognized, but are poorly incorporated. The high discounting commonly employed in applications of neoclassical economic theories does not allow the possibilities beyond a decade or two in the future to influence present decisions.

Economists know that success in achieving financial return from fast dynamics leads to slowly emergent, nearly hidden, changes in deeper and slower structures, changes that ultimately trigger sudden crisis and surprise. But the complexities that arise are such that many modern economists are frustrated in their attempts to understand the interactions between fast- and slow-moving variables that create emergent dynamics (Stiglitz 1998). Chapters 7,8 and 10 begin to expose the consequences and solutions.

Ecology

Ecosystem ecologists, on the other hand, have made it plain for a long while that some of the most telling properties of ecological systems emerge from the interactions between slow-moving and fast-moving processes and between processes that have large spatial reach and processes that are relatively localized. Those interactions are not only non-linear; they generate alternating stable states and normal journeys of biotic and abiotic variables through those states. Those journeys -- measured in decades and centuries- maintain the diversity of species, spatial patterns and genetic attributes. The journeys maintain the resilience of ecological systems.

Variability in ecosystems is not merely an inconvenient characteristic of these productive, dynamic systems. It is essential for their maintenance. Ecologists are beginning to understand the way that variability and diversity are created by and sustain ecosystems because of interactions among slow and fast processes, large and small. Both Chapters 2 and 3 review and expand that understanding.

Reducing variability and diversity produce conditions that cause a system to flip into an irreversible (typically degraded) state controlled by unfamiliar processes.

But ecologists limit their understanding and propose inadequate actions by largely ignoring the realities of human behavior, organizational structures and institutional arrangements that mediate the relationships between people and nature.

Institutions and Organizations

Institutional and organizational theory and analysis does consider such features, but in a largely static sense. It often stops short of the required integration of the three fields of inquiry. Institutional and organizational theory currently provides a fascinating understanding of the variety of arrangements and rules that have evolved in different societies to harmonize the relation between people and nature. Social scientists have gone far in describing the way people store, maintain and use knowledge in stable circumstances. But they have not attended to the processes that control and maintain these institutions dynamically, the kind of dynamic causation that is present in economics and ecology.

In order to plan for sustainability, we need to know, and we need to integrate, how information is evaluated and counter-productive information rejected. How is new "knowledge" created from competing information sources and incorporated with useful existing knowledge? Which processes create novelty, which smother innovation, which foster it? Those questions are explored advanced in Chapter 4 and 13. Neither ecology, nor economics nor institutional theory now deals well with these fundamental questions of innovation, emergence and opportunity. That is what evolutionary theory is about.

Evolution and Complex Systems

The emergence of novelty that creates unpredictable opportunity is at the heart of sustainable development (Holling 1994). Biological evolutionary theory -- which can be expanded to include cultural evolution -- deals with just this process. The new field of complexity studies sees ecological, economic and social systems as being similar to biological processes that generate variability and expose the patterns that result to selective forces. But, like each of the other fields, the representations are partial. They are detached from deep knowledge of the key natural and human processes, and from convincing tests of the adequacy and credibility of the results.

In this book we argue that the process of developing policies and investments for sustainability requires a world view that integrates ecological with economic with institutional with evolutionary theory -- that overcomes disconnects due to limitations of each field. But as compelling and easy as it is to wag a finger at disciplinary gaps, they are clearly not the only reason for unsustainable practices. There are other, deeper limitations that arise from world views that people hold. These world views are also partial representations of reality: representations that are valuable because they provide temporary certitude to allow action, but whose partial nature ultimately exposes their inadequacy. They are caricatures of aspects of reality.

Caricatures of Nature

Although some of the failures of complex resource systems are due to limitations in disciplinary theories and experience, others can be traced to differences among the world views or myths that people hold. In this section we identify at least five such caricatures that underlie explanations of how nature works and the implications of those assumptions on subsequent policies and actions (Figure 1-1). Each of these caricatures or myths leads to different assumptions about stability, different perceptions of the processes that affect that stability and different policies that are appropriate (Table 1-1). We begin with the most static view: that of a nature lacking stabilizing forces- "Nature Flat".

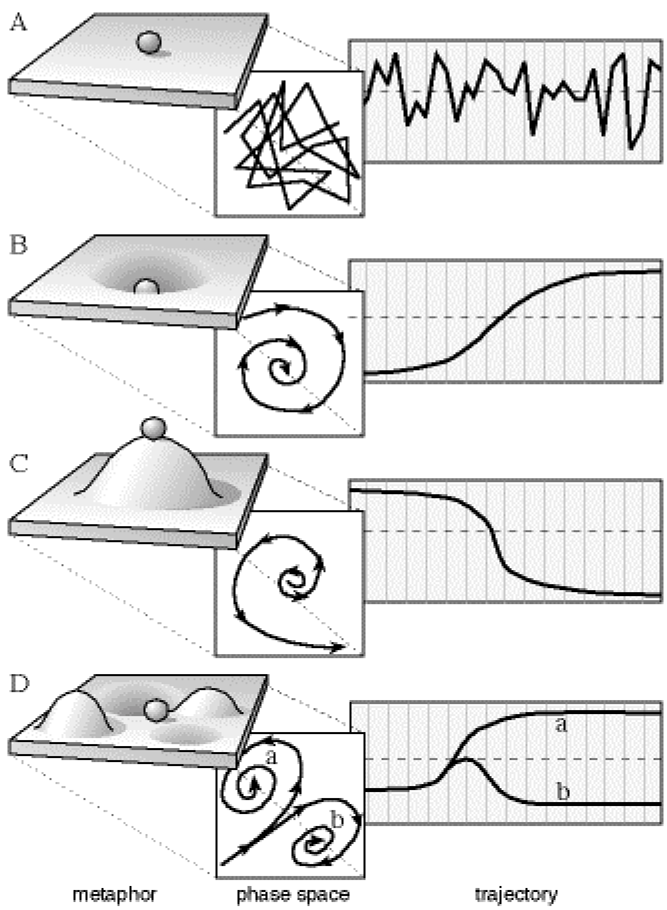

Figure 1.1

Table 1-1. Characteristics of alternative views or myths of nature

	Stability	Processes	Policies	Consequences
Flat Nature	None	Stochastic	Random	Trial and Error
Balanced Nature	Globally stable	Negative feedback	Optimize or Return to equilibrium	Pathology of Surprise
Anarchic Nature	Globally unstable	Positive feedback	Precautionary principle	Status Quo
Resilient Nature	Multiple stable states	Exogenous input and internal feedback	Maintain variability	Recovery at local scales or Adaptation; Structural surprise
Evolving Nature	Shifting stability landscape	Multiple scales and Discontinuous structures	Flexible and actively adaptive, probing	Active Learning and New Institutions

Nature Flat. In this view, "flat" is used to describe a system in which there are few or no forces affecting stability. There are therefore few limitations on the ability of humans to change nature. There are no feedbacks or consequences from nature of those actions. It is much like rolling a ball around on cookie sheet. (Fig. 1-1 A). The processes that affect the position of the ball, i.e. state of nature, are random or stochastic. In such a view of nature, policies and politics are random as well, often described as 'garbage can' politics (March and Olsen, 1989; Warglien and Masuch 1996). It is a nature that is infinitely malleable and amenable to human control and domination if only the "right" values and the "right" timing are chosen. The issues of resource use, development, or control are identified as issues that are exclusively ones of human action, ones that can be resolved by community activism or stakeholder control. Alternatively, it can be a view of cornucopian nature where human ingenuity and knowledge surmount all obstacles to produce exponential growth. Such a "flat worlder" view is not wrong, just incomplete. There are indeed, strong stochastic elements.

Nature Balanced. The second myth is a view of nature existing at or near an equilibrium condition (Fig. 1-1 B). That equilibrium can be a static one or a dynamic one. Hence if nature is disturbed, it will return to an equilibrium through (in systems terms) negative feedback. Nature appears to be infinitely forgiving. It is the myth of maximum sustainable yield and of achieving fixed carrying capacities for animals and humanity. It imposes a static goal on a dynamic system. This view of nature underpins prescriptions for logistic growth, where the issue is how to navigate a looming and turbulent transition - demographic, economic, social and environmental - to a sustained plateau. This is the view of several institutions with a mandate for reforming global resource and environmental policy - of the Brundtland Commission, the World Resources Institute, the International Institute of Applied Systems Analysis, and the International Institute for Sustainable Development. Many individuals in these and similar institutions are contributing skillful scholarship and policy innovation. They are among some of the most effective forces for change, but the static assumptions can create the very surprise and crisis they wish to avoid. The "balanced worlder" view is also not wrong- just incomplete. There are indeed, forces of balance in the world.

Nature Anarchic. If the previous myth is one where the system stability is defined as a ball at the bottom of a cup, this myth is one of a ball at the top of a hill (Fig. 1-1 C). It is globally unstable. It is a view dominated by hyperbolic processes of growth and collapse, where increase is inevitably followed by decrease. It is a view of fundamental instability where persistence is only possible in a decentralized system where there are minimal demands on nature. It is the view of Schumacher (1973) or some environmentalists. If the first Nature Flat view assumes that infinitely ingenious humans do not need to learn anything different, this view assumes that humans are incapable of learning. This is implicit in the writings of Tenner (1996), where he argues that all technology that is unleashed will eventually 'bite-back'. This view presumes that small-is-beautiful, because the inevitable catastrophe of any policy must be kept localized. It is a view where the precautionary principle of policy dominates, and social activity is focussed on maintenance of the status quo. The "anarchist worlder" view is also not wrong- just incomplete. There are indeed destabilizing forces and there is a value in diversity.

Nature Resilient. The fourth is a view of multi-stable states, some of which become irreversible traps, others alternating states that are experienced as part of the internal dynamics (Fig. 1-1 D). Those dynamics result from cycles organized by fundamentally discontinuous events and non-linear processes. There are periods of exponential change, periods of growing stasis and brittleness, periods of readjustment or collapse and periods of reorganization for renewal. Instabilities organize the behaviors as much as do stabilities. That was the view of Schumpeter's (1950) economics and it has more recently been the focus of fruitful scholarship in a wide range of fields- ecological, social, economic and technical. These dynamics are the ones argued for ecosystems (Holling, 1986). They have similarities in Harvey Brook's view of technology (1986), recent views of the economics of innovation and competition (Arthur, Durlauf and Lane, 1997), Mary Douglas' (1978) and Mike Thompson's (1983) view of cultures, Don Michael's view of human psychology (1984) and Barbara Tuchman's (1978) and William McNeil's (1979) view of history. It is a view of multiple stable states in ecosystems, economies and societies and of policies and management approaches that are adaptive. But this view presumes a stationary stability landscape- stationary underlying forces that shape events. In this case, our cookie sheet has been molded and curved in three dimensions, but its basic contours are fixed over time (Fig 1-1 D). This "resilient worlder" view is also not wrong, just incomplete. There are, indeed, cycles of change, that can move variables among stability domains, but those very movements contribute to the apparent fixed nature of the contours. Constrain those movements through policy actions and the contours shift, as slow variables change. That can precipitate a more structural kind of surprise that is a consequence of successful, but myopic policy. Many of the examples of the pathology of resource management and regional development are just those kinds of structural surprises.

Nature Evolving. The emerging fifth view is evolutionary and adaptive. It has been given recent impetus by the paradoxes that have emerged in successfully applying the previous more limited views. Complex systems behavior, discontinuous change, chaos and order, self-organization, non-linear system behavior and adaptive evolving systems are all the present code words characterizing the more recent activities. It is leading to integrative studies that combine insights and people from developmental biology and genetics, evolutionary biology, physics, economics, ecology and computer science. Profound innovations have been created and led by John Holland in his applications of genetic algorithms and complex adaptive system theory. His more recent work on a simple, highly visual model that illustrates the creation of complex structures by natural selection (Holland 1995), which he called ECHO, presents a way to explore the generation and selection of novelty in mathematical, economic and social systems. In economics, some examples of early developments are in Anderson, Arrow, and Pines (1988). A nice review of later work is Sargent (1993), and a current collection of articles is presented in Arthur, Durlauf, and Lane (1997). Marco Janssen extends and applies those approaches to explore changing perspectives on future behavior in Chapter 9. It is a view of an actively shifting stability landscape with self-organization (the stability landscape affects behavior of the variables and the variables, plus exogenous events, affect the stability landscape). Levin's recent book, Fragile Dominion (1999), gives an accessible and effective treatment of present adaptive, complex systems views for ecology.

Nature Evolving is a view of abrupt and transforming change. It is a view that exposes a need for understanding unpredictable dynamics in ecosystems and a corollary focus on institutional and political flexibility. We cannot, at this stage, invent a simple diagram to add this myth to those shown in Fig. 1-1. In a sense, that is the purpose of the book- to develop a sufficiently deep understanding of Nature Evolving that its essential behavior and the relevant policies can be captured in a few paragraphs, a few simple models of real situations and a simple set of suggestive diagrams. Subsequent chapters provide the understanding to do just that using a theoretical framework we call panarchy

Many of the examples of successful resource exploitation followed by collapse are based on the above mentioned myths of nature. The concepts of stability and resilience embedded in these caricatures can be given meaning in the metaphor of raft described in Box 1-2. These myths are useful underpinnings for understanding and action. Yet they reveal a paradox that goes back hundreds of years in thought. That is, if human exploitation leads to resource collapse, why haven't all ecological systems collapsed, and why are we humans still here? We discuss that paradox in the following section.

Box 1-2 .The Raft- a Metaphor of Stability and Resilience

D. Ludwig

The concept of stability refers to the tendency of a system to return to a position of equilibrium when disturbed. For example, if a weight is added suddenly to a raft floating on water the usual response is for the weighted raft to oscillate, but the oscillations gradually decrease in amplitude as the energy of the oscillations is dissipated in waves and eventually in heat. The weighted raft will come to rest in a different position than the unweighted raft, but we think of the new configuration as essentially the same as the old one. The system is stable.

If we gradually increase the weight on the raft, eventually the configuration will change. If the weight is hung below the raft, the raft will sink deeper and deeper into the water as more and more displacement is required to balance the higher gravitational force. Eventually the buoyant force cannot balance the gravitational force and the whole configuration sinks: the system is no longer stable. On the other hand if the weight is placed on top of the raft, the raft may flip over suddenly and lose the weight and its other contents long before the point at which the system as a whole would sink. This sudden loss of stability may be more dangerous than the gradual sinking because there may be little warning or opportunity to prepare for it. We may think of the raft system as losing its resilience as more weight is placed on top of it.

Is the raft likely to experience a gradual loss of stability or a sudden one? In order to decide whether a system is stable or not, we must first specify what we mean by a change in configuration or loss of integrity. If we don't care whether the raft flips over when weighted, then there is no problem of sudden loss of stability for the floating raft. We must also specify the types and quantities of disturbances that may affect the system. Suppose that a fixed weight is placed on top of an occupied raft. If the occupants of the raft move about, the raft may float at a slightly different angle, but if they move too far or all at once, the raft may tip. The range of possible movements of the occupants that do not lead to tipping is called the domain of stability or domain of attraction of the upright state. If the amount of the fixed weight is gradually increased, the balance becomes more precarious and hence the domain of attraction will shrink. Eventually the weight becomes large enough so that there is no domain of stability.

The preceding example makes a distinction between the weight loading the raft and the positions of the occupants. If the amount of the weight changes very slowly or not at all, we may think of the ``system'' as consisting of the raft and weight. The occupants change position relatively quickly, and these changes may be thought of as disturbances of the system. On the other hand we may adopt a more comprehensive point of view and view the raft, the weight and the occupants as a single system. If the occupants organize themselves to anticipate and correct for external disturbances, then the system may be able to maintain its integrity long enough for them to achieve their objectives. Another possible response to disturbance might be to restructure the raft itself. If it were constructed of several loosely coupled sub-units, then excessive weighting or a strong disturbance might flip one part of the system, but leave the rest intact. Such a structure might not require as much vigilance to maintain as the single system raft.

The resilience of the raft cannot be determined outside its social and institutional context. The occupants of the raft might have differing rights and objectives. Those who stand to benefit most from heavy loading may tend to minimize the risks of tipping under load. Those who have most to lose from a loss of stability may favor a very cautious approach. How will decisions be made about the loading and configuration of the raft? Who are the stakeholders, i. e. whose interests must be taken into account when alternative policies are considered? Does the raft have an owner? How do his rights and obligations compare with the rights and obligations of the occupants? Is there a governmental agency in charge of regulating rafts? Are there interest groups who would prefer that rafts not be allowed on the waterways? The eventual fate of the raft will depend upon the physical characteristics of the raft, the environment in which it is deployed, and the social and political structure in which it is embedded.

Why has the world not collapsed?

Part of the answer to this paradox is that natural ecological systems have the resilience to experience wide change and still maintain the integrity of their functions. The other part of the answer lies in human behavior and creativity. People do learn, however spasmodically. Change and extreme transformations have been part of humanity's evolutionary history. People's adaptive capabilities, have made it possible not only to persist passively, but to create and innovate when limits are reached.

The reason for the astonishing resilience of natural ecosystems can be found in examining the scales at which processes (including humans) operate to control the system. For example, in most terrestrial systems, geophysical controls dominate at scales larger than tens of kilometers. At scales smaller than this, biotic processes, interacting with abiotic ones, can control structure and variability. They produce volumes and patterns of vegetation and soil, for example, that moderate external extremes of temperature, conserve moisture and nutrients, and even affect regional climate and the timing of seasons. These are also the scale ranges where human land use transformations occur so that the arena where plant and animal controlling interactions unfold is the same arena where human activities interact with the landscape. That is why human population growth and development is so inexorably interconnected with terrestrial ecosystem resilience.

The controls determined by each set of biotic structuring processes within terrestrial ecosystems are remarkably robust and the behaviors resulting are remarkably resilient. That robustness comes from functional diversity and spatial heterogeneity in the species and physical variables that mediate the key processes that structure and organize patterns in ecosystems and landscapes. The stability domains that define the type of system (e.g. forest, savanna, grassland, or shrub steppe) are so large that external disturbances have to be extreme and/or persistent before the system flips irreversibly into another state. Except under extreme climatic conditions, Mother Nature is not basically in a state of delicate balance. If She were, the world would indeed have collapsed long ago.

The myths of Nature Balanced and Nature Anarchic therefore have to be expanded to include Nature Resilient. So long as we only accept the axiom that the balance between exponential growth and environmental/ecological limits generates an inexorable Malthusian determinism , then the only behavior of interest is that near equilibrium. In contrast, when we only perceive external physical variability and passively adapting biota, then Nature Anarchic is the logical image and spatial heterogeneity emerges as the critical ingredient for persistence in a world of locally unstable equilibria.

When, however, we perceive a structuring and controlling role for key clusters of biota at small and fast scale ranges, for zootic and abiotic processes like insect outbreaks, large ungulate grazing, storm and fires at intermediate scale ranges and for geophysical processes at large scale ranges, then the image of Nature Resilient emerges. Such an image incorporates the principles of negative feedback regulation of Nature Balanced and of stochastic physical variation of Nature Anarchic, but adds principles of biotically induced variation and self-organization. At the scales from leaf to landscape, the biota can create conditions that supports the very biotic processes themselves.

In the view of Nature Resilient, behaviors near equilibrium and the traditional mathematical tools for local stability analysis are irrelevant. Populations assume trajectories that are dynamically unstable . The critical focus then becomes conditions at the boundaries of stability domains, the size of those domains and the forces that maintain those domains. The paper that originally introduced this contrast between systems resilience and equilibrium stability (Holling 1973) was written as an antidote to the narrow view of fixed, equilibrium behavior and of resistance of populations to local perturbation. Those narrow, essentially static notions have provided the foundations for the now discredited goals of maximum sustained yields of fish populations or of fixed carrying capacity for terrestrial animal populations. The success of achieving such goals squeezes out variability and resilience is lost. Periodic crises result.

Thus part of the answer to the question "why has the world not collapsed?" is that natural ecological systems have the resilience to experience wide change and still maintain the integrity of their functions.

But the other part of the answer lies in human behavior and creativity. Change and extreme transformations have been part of humanity's evolutionary history. People's adaptive capabilities have made it possible not only to persist passively, but also to create and innovate when limits are reached. At its extreme, these attributes underlie the economists' presumptions of peoples' unlimited capacity to substitute for scarce materials and to develop successful remedial policies incrementally once the need is apparent. The themes of human creativity and novelty are developed in subsequent chapters of this volume.

Partial Theories and Partial Explanation

We search for explanations that are simple and general. Can complex adaptive systems help us understand ecological, economic and social systems separately and as they interact? By understand we mean distinguish that which is predictable (even if uncertain) from that which is emergent and inherently unpredictable. The test of understanding is whether we can organize specific properties of many, qualitatively different, specific examples. Can we define adaptive responses and policies that benefit from and perhaps even create useful unpredictability? That is what adaptive policy is about.

There are not too few theories for these systems. There are too many. They are all correct or mostly correct, but incomplete. For example, in ecology the notion of Clementsian succession was a typical equilibrium theory that saw ecosystem succession proceeding from establishment of pioneer species that withstand extremes of microclimate, to climax species whose tight competitive relationships precluded other species. The theory was not wrong, but incomplete, since empirical tests of that theory exposed a much more variable progression, a rich range of individual species responses to micro climate and soils, the existence of a number of different end states and the role of disturbance as part of ecosystem renewal.

In economics, the pure market model is an equilibrium theory where demand and supply reach stable equilibrium prices when marginal changes just balance. It is not wrong, but we know that market imperfections occur when the simplifying assumptions are violated. Those violations become more pronounced as the scale of human impacts on the environment increase in extent and intensity (Arrow et al. 1995). That view of the market is not too different from the theory of island biogeography in ecology, where the equilibrium number of species on islands is seen as the balance between species immigration and extinction. The theory is not wrong, but incomplete, because empirical checks demonstrate that the theory can be a poor predictor. The list could go on- density dependent regulation in population dynamics, competition in community ecology, field theory in economics, garbage-can models in decision theory.

These theories are partial truths. Once proposed, they stimulate fruitful inquiry. As a consequence, their partial nature is exposed and extension and expansion of theory proceeds. Parental affection for theory by those who form them and the psychology of adherents makes those extensions contentious. Critics became extreme; straw-man caricatures are established, and roundly defeated. The best of the defenders resist throwing the baby out with the bath water and are affronted by the often inappropriate attacks when the leading edge of theory formation has often been there earlier. That is where we see the present debates about economics from environmental perspectives. We hope that we can clarify and open fruitful inquiries through the cooperation of ecologists, economists and social scientists displayed in this book.

In our quest, we would like to discover ways to integrate and extend existing theory to achieve a requisite level of simplicity, just complex enough to capture and explain the behaviors we see. Those include explanations of discontinuous patterns in space, time and structure and explanations for how novelty emerges, is suppressed, or is entrained. For prescriptive purposes we also seek adaptive ways to deal with surprise and the unpredictable. We concentrate on adaptive approaches that do not smother opportunity, in contrast to control approaches that presume that knowledge is sufficient and that consequences of policy implementation are predictable.

So -- requisite simplicity, but generality? What is the context within which the theory is functional? Generality is desired -- but also to be feared. It is to be feared because once a theory is formed, once it seems to resolve paradoxes and once it passes some empirical tests, proponents are sorely tempted to extend its application beyond its natural context. That is particularly true if the theory emerges in the natural sciences and is applied to humans. The history of science is replete with such examples- some disastrous (social Darwinism), others usefully provocative (sociobiology and evolutionary psychology) and still others wonderfully over-ambitious (complexity theory?). It is not always so bad to reach beyond the theory's real grasp because the science-based efforts at least have a process, however lurching and inefficient, to test them. But caution and sharp questioning is essential.

We encountered this issue when faced with the temptation to extend a theory of adaptive cycles developed for ecosystems dynamics and renewal (Chapter 2) to other systems, particularly organizational ones (Gunderson et al 1995), business ones (Hurst 1995) and more generally, social and political ones (Holling and Sanderson 1996).

That led to an expansion that recognized that the adaptive cycles were nested in a hierarchy across time and space (Gunderson et al. 1995). That expansion seemed to explain how adaptive systems can, for brief moments, generate novel recombinations that are tested during longer periods of capital accumulation and storage. These windows of experimentation open briefly, but the results do not trigger cascading instabilities of the whole because of the stabilizing nature of nested hierarchies. In essence, larger and slower components of the hierarchy provide the memory of the past and the distant to allow recovery of smaller and faster adaptive cycles. In ecosystems, for example, seed banks in soil, biotic heritages and distant pioneer species are all critical accumulations from the past for present renewal.

That expansion did not help us avoid the pitfall of overstretched generality, however; rather it made it worse. That was the motive that initiated this book. The expansion seemed to explain everything. It applied to theories of non-living systems, such as plate tectonics. The sequence of phases in the cycle were all there: The establishment of the plates from magma extruding at the mid-Atlantic ridge, slow movement of the plates encountering continental edges, material subducting back to be melted and the elements resorted in new episodes of mineral formation in mountain building. In addition, too many other systems seemed equally to fit the heuristic model of change: cell development, meiotic reproduction, ecosystem formation, evolution, organizational stasis and transformation, political and social processes. If a theory explains everything it explains nothing. What are needed are tough specific predictions that can be tested empirically. That is possible for the natural science components systems but much less so for social components.

Seeking Simplicity in Quest of a Theory of Adaptive Change

Our goal for this book was simple: to develop and test theories that explain transformational change in systems of humans and nature. Our method is to develop sufficiently simple theory through assimilation and integration.

We present two targets for integration. One is to integrate dynamics of change across space from local, to regional, to global and over time from months to millennia. Traditions of science have tended to simplify by focussing on one scale. However, growing human impacts on the planet's atmosphere and on international economic patterns have stimulated efforts over the last decade to explore cross-scale influences (Levin 1992, 1999). Examples are impacts of climate change on regional ecosystems and on local human heath, or of economic globalization on regional employment and the environment, or of emergence of new diseases, like AIDS, and their spread internationally. An economist might say that the world's local and regional ecological, economic and social systems are increasingly influenced by externalities (Arrow et al. 1995, Levin, et al. 1998). An ecologist might say that they have become increasingly coupled, so that fast and slow processes, local and distant ones cannot be treated separately (O'Neill et al. 1998). Increasingly, local problems of the moment can have part of their cause located half a planet away and emerging from half a century of slow changes.

The processes that drive or mediate the spatial intensification range from fast processes of vegetative growth in ecosystems and of economic production in economies, to slow processes of geomorphological change and of human cultural and political development. The processes we need to understand, and in some way integrate, literally cover months to millennia, meters to tens of thousands of kilometers.

This integration builds on prior work (Gunderson et al. 1995) that identified the linkages between system dynamics and scale-the roots of the term panarchy. The term was coined as an antethesis to the word hierarchy (literally sacred rules). Our view is that panarchy is a framework of natures rules, from the Greek god of nature- Pan. Chapters 2 and 3 focus on this integration, that of developing theories of cross scale dynamics and testing specific examples of ecological, social and organizational change.

The second target for integration was to integrate across disciplines to better understand systems of linked ecological, economic and institutional processes. Again, the expanding influence of human activity intensifies the coupling between people and systems of nature so that neither can be understood in isolation (Vitousek 1997, Holling 1994).

The second goal of interdisciplinary integration- of how linked systems of nature, economies and institutions function- is a major focus of Chapters 7, 8, 9 and 10 where mathematical representations of these integrated systems are explored. The consequences of that disciplinary integration are summarized as conclusions in Chapter 15 and synthesized in Chapter 16.

We hope that our approach in the remainder of this volume embodies the major elements of a heuristic theory. It draws on theories of adaptive change in biological and ecological systems, of self-organization in complex systems, of rational actor models in economics and of cultural evolution. We are promulgating regional tests of our approach; we have posed the test questions; we are building a network of test takers -- of practitioners, scientists and policy decision-makers who wish to contribute to a sustainable future for regions and for the planet. It is a future that encourages innovative opportunity for people to learn and prosper, that incorporates responsibility to maintain and restore the diversity of nature, and that is based on a just and civil society. We hope this volume contributes to such a future.